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CONTENTS

Page	
186	Frontispiece—Main bay of the new Heavy Turbine Shop at the Fraser & Chalmers Engineering Works, Erith
187	New Heavy Turbine Shop at Erith *By F. L. Griffiths*
197	The EW54 Germanium Junction Rectifier *By R. D. Knott and J. I. Missen*
209	Diesel-Electric Shunting Locomotives for British Railways *By J. C. Turrall and W. E. Lewis*
219	Electrification at Jan Smuts Airport *By H. H. James*
230	Nuclear Power for Electricity Generation *By R. N. Millar*
232	Secondary Standard Lamps for Photometric and Colorimetric Purposes *By R. E. Leeds and G. T. Winch*
236	Sodium Light for Coal Picking

COVER PICTURE

An artist's impression of a G.E.C. atomic power station of the future.

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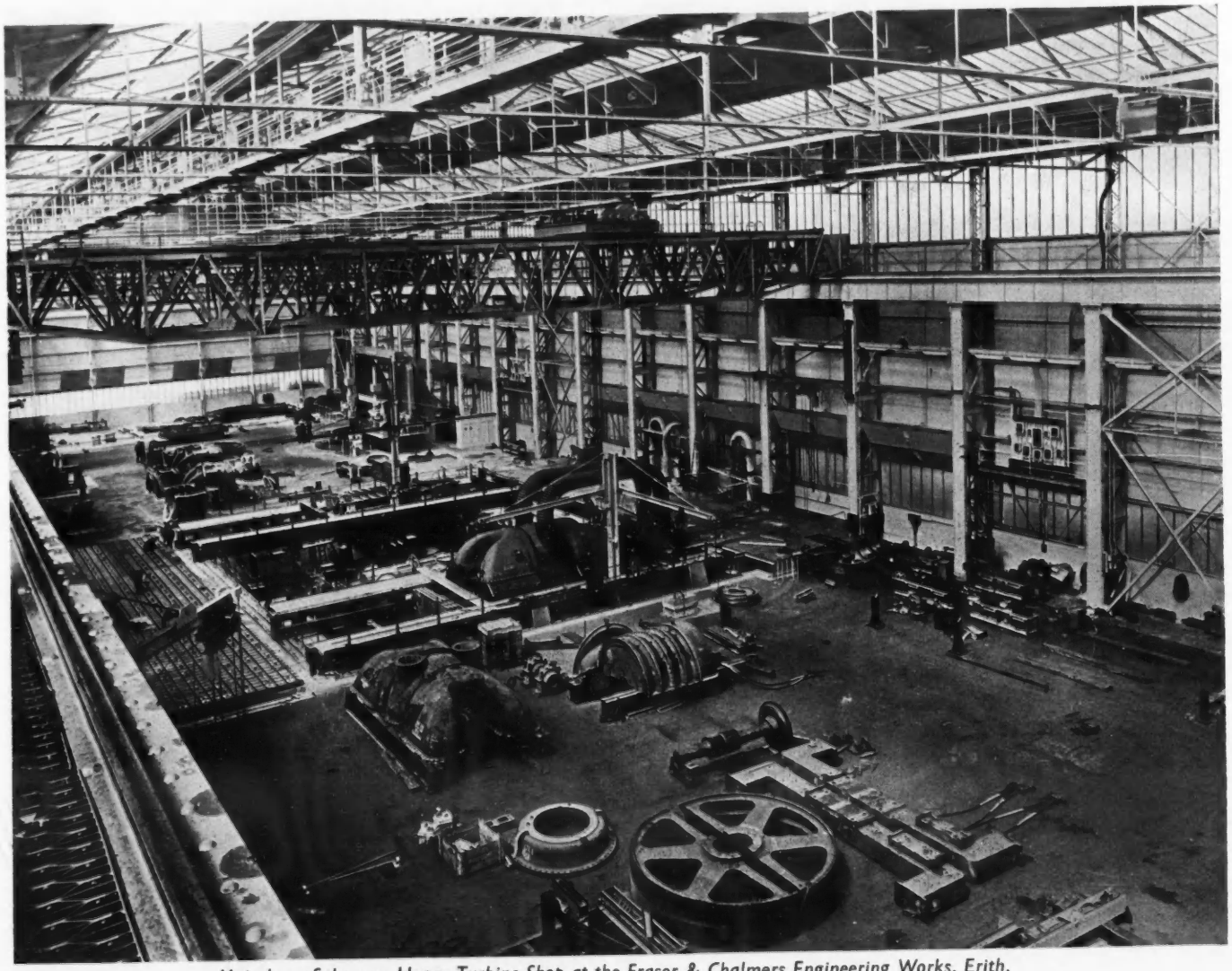

Main bay of the new Heavy Turbine Shop at the Fraser & Chalmers Engineering Works, Erith.

New Heavy Turbine Shop at Erith

By F. L. GRIFFITHS
Fraser & Chalmers Engineering Works.

A NEW Heavy Turbine Shop, designed for the erection and testing of the largest machines at present envisaged for power generation, was opened on July 15 at the Fraser & Chalmers Engineering Works of the G.E.C. at Erith, Kent. The opening ceremony was performed by the Rt. Hon. Lord Citrine, P.C., K.B.E., Comp.I.E.E., LL.D., Chairman of the Central Electricity Authority.

Since the war there has been an increasing demand for electrical power in all parts of the world, and a trend towards the use of turbo-alternator sets of higher individual capacity. The new shop has therefore been designed to increase substantially the manufacturing capacity of the Company's works at Erith, and to provide facilities on the necessary scale for building machines up to ratings as high as 400 MW when required in the future.

Work began on the excavations for the shop in February, 1953, and preparatory operations afforded an opportunity for the realignment of nearly four miles of railway sidings. Many existing services running beneath the site had to be diverted. In excavating for the condenser pit it was necessary to build a pump house integral with a reinforced concrete well 20 ft. below ground level in order to drain water from a layer of chalk at this depth.

CONSTRUCTIONAL FEATURES.

The new shop (fig. 1) is a steel fabricated building, brick-filled up to 13 ft. from the ground. Above this

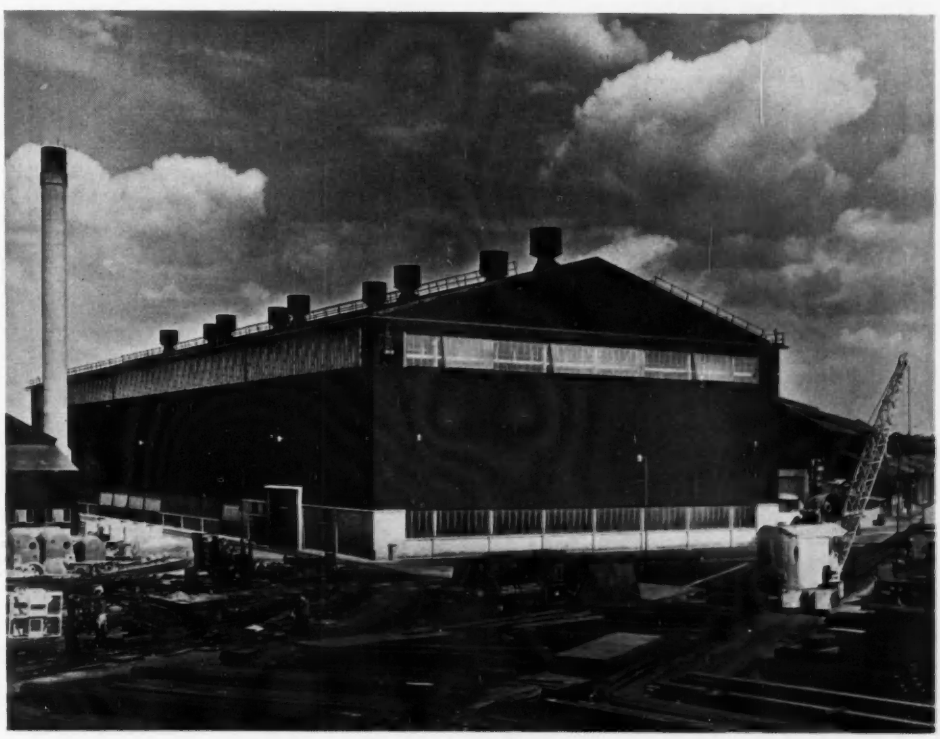

Fig. 1.—Exterior of shop.

Main bay of the new Heavy Turbine Shop at the Fraser & Chalmers Engineering Works, Erith.

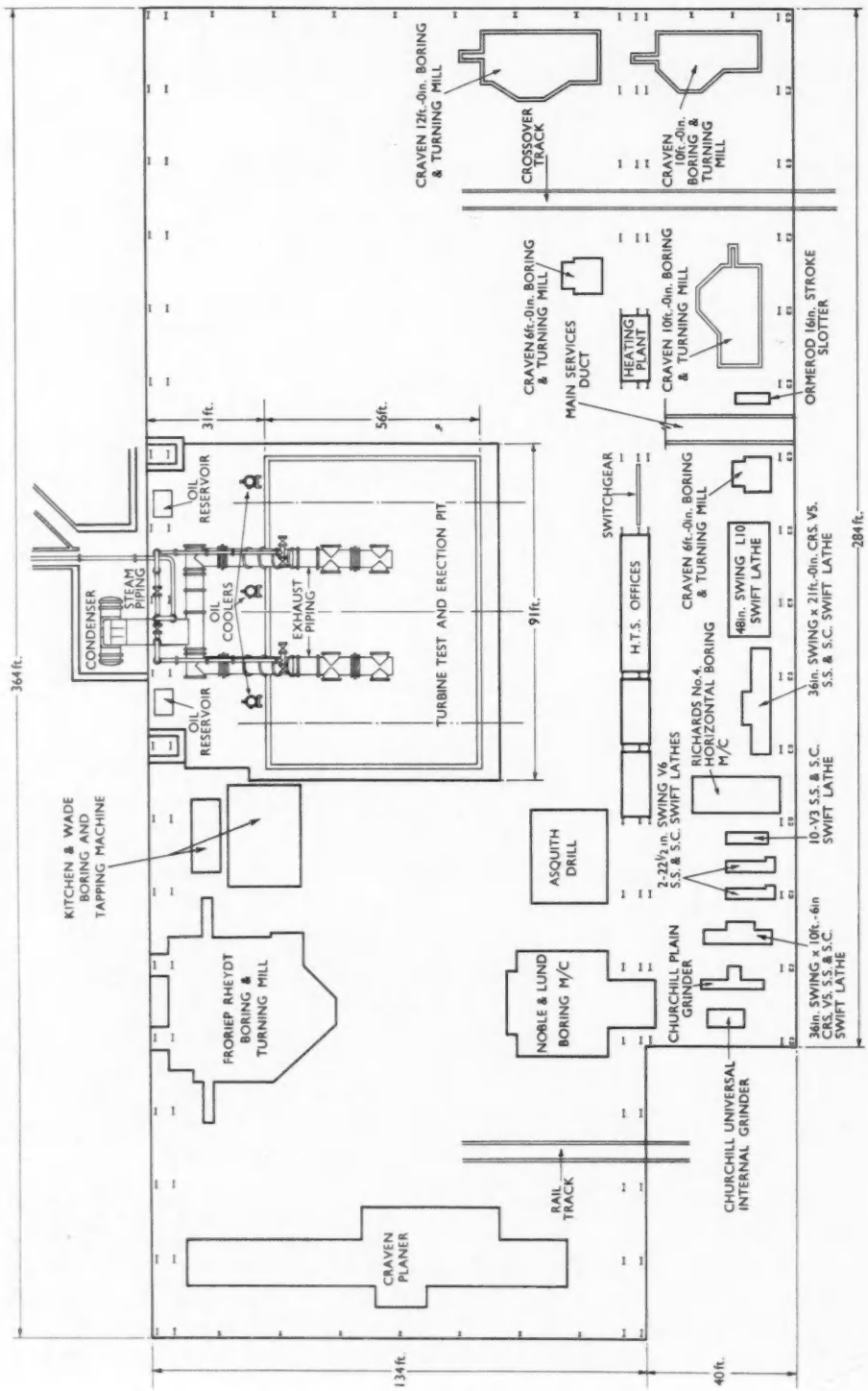

Fig. 2.—Ground plan of the shop and annexe.

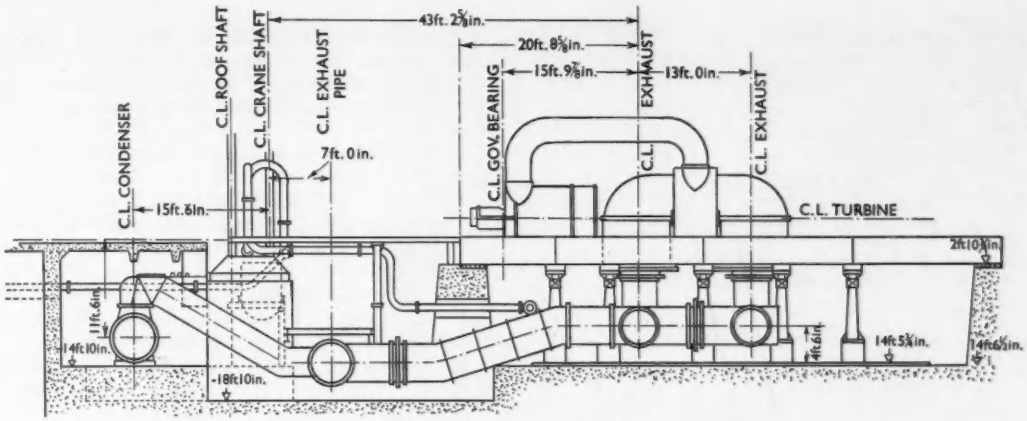

Fig. 3.—Method of mounting machines on test bed.

level the walls and roof are covered with protected metal sheeting and lined with plasterboard.

The shop consists of a main bay 364 ft. long and 134 ft. wide, with a machine tool annexe on one side measuring 284 ft. by 40 ft. (fig. 2). Total floor area is 59,044 sq. ft. In the main bay the height to the eaves is 59 ft., and in the annexe 37 ft. The height to the apex of the roof in the main bay is 82 ft.

The roof guttering has been designed to form a walkway with handrails right round the building level with the eaves. Further walkways are provided at the middle and the apex of the roof. There is also a continuous runway round the building from which cradles can be suspended and shifted as desired for cleaning and repairing the upper windows and sheeting and for painting.

Two 60-ton Wharton cranes with a span of 120 ft.

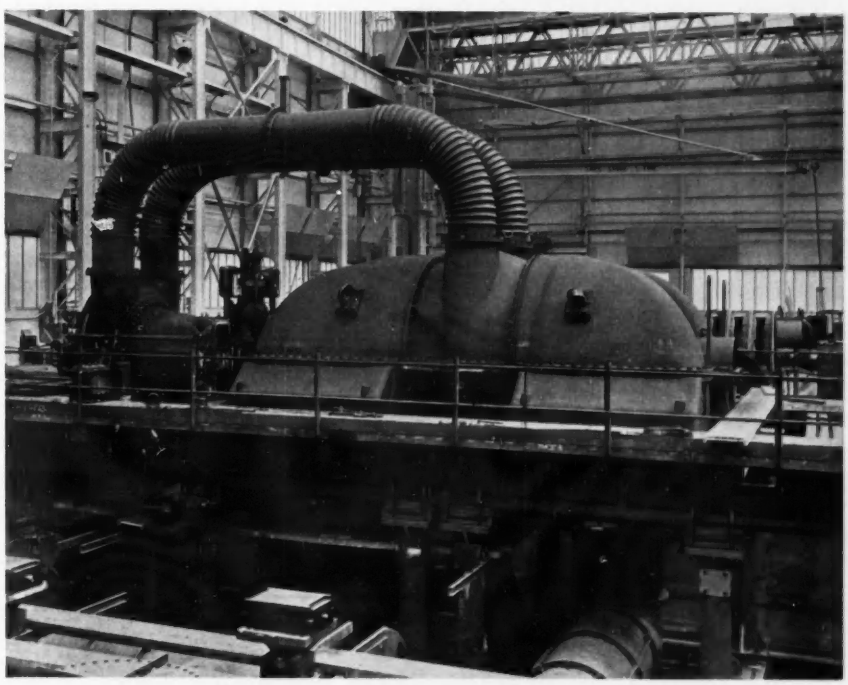

Fig. 4.—A 60 MW turbine for Ince power station on the bed.

run on rails extending the full length of the shop at a height of 43 ft. Both can be operated in tandem for a lift of 120 tons. In addition to the 60-ton main hoist, each crane has a 20-ton auxiliary hoist and is powered by four 500 volt D.C. motors operating the two hoists, and the longitudinal and cross traverse. Two of the roof trusses at each end of the main bay are specially designed to accommodate a lifting beam for removal and replacement of crane equipment for servicing.

TURBINE TEST PIT.

The pit on which turbines are erected and tested (figs. 3 and 4) is 91 ft. long and 87 ft. across at the top. The depth of the turbine pit itself is 13 ft. 1 in., and it adjoins a pit 17 ft. deep for the condenser. Both pits are of reinforced concrete, the walls of the turbine pit being 5 ft. thick in places. Three machines of any of the capacities now current or planned can be erected simultaneously, the bed of the pit being designed to allow the utmost latitude in this respect both as regards the size of the turbines and the positions of the supporting points. For this purpose the whole of the base of the bed is equipped with plates slotted with tee-slots to receive the cast-iron stools, 30 in. square, on which the supporting columns stand.

The columns, 26 in. square at the top, are of a uniform height of 8 ft. 4 in. They support the girders spanning the pit through register blocks designed for packing of variable depth to provide fine adjustment of level. The girders on which the machines are bolted are in four sections, three of them 17 ft. long and the fourth, at the frame end, 11 ft. long. All sections are 3 ft. 4 in. deep and 18 in. wide. Serving the pit are three 10 cwt. electric hoists mounted on 20 ft. radius swing arms along which they can be traversed manually; the arms are pivoted from a common vertical girder. Also six 50 cwt. cranes on 18 ft. radius jibs are fitted.

A cast-iron tee-slotted soleplate formed of twenty-one individual castings, each measuring 9 ft. 3 in. by 12 ft., has been provided at one end of the pit, so that extra length is available for running alternator rotors on test if required. This area is also available for bolting-up sub-assemblies.

Free areas of the shop floor are paved with grain-on-end wood blocks to provide a suitable surface for handling castings.

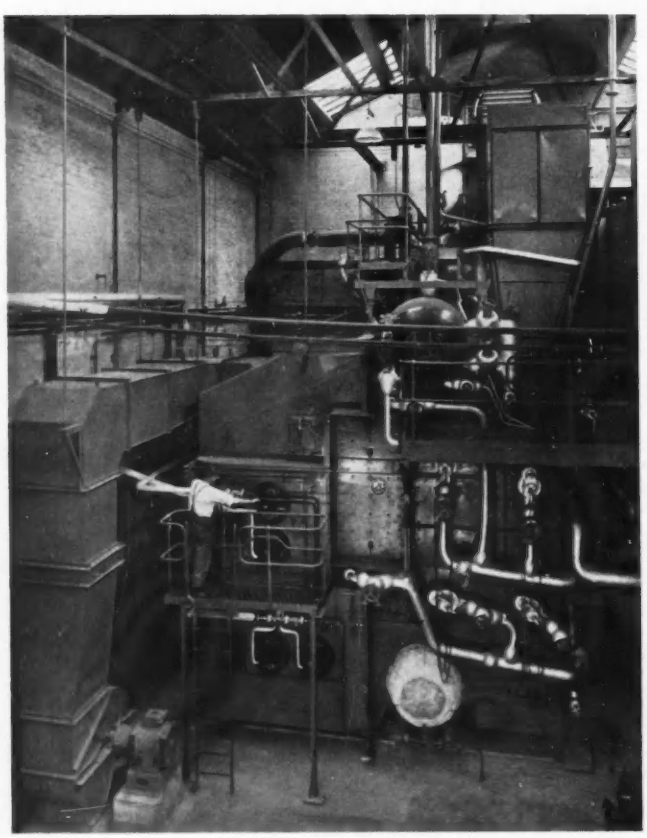

Fig. 5.—Twin-furnace oil-fired boiler.

BOILER INSTALLATION.

To supply steam for the new shop a boiler of special design, constructed by International Combustion Ltd., has been installed (fig. 5). This is a twin-furnace, oil-fired boiler, differentially fired, and provides steam at any predetermined temperature up to 875 deg. F. The capacity of the boiler is 45,000 lb. per hr. at 665 lb. per sq. in. Provision is made for a second boiler to be installed at a later date.

The boiler is fired with heavy fuel oil. Four oil burners are fitted in each of the two furnaces. The lower furnace could supply any quantity of steam up to full load at a temperature just above the saturation level. The top furnace, containing the superheater, provides the measure of superheat required for machines under test. Gases from this furnace pass over into the boiler proper. The superheater is arranged as a primary and secondary unit.

In order to obtain final adjustment of the temperature of steam supplied to the test bed, a small by-pass is arranged to pass a quantity of steam through a coil in the lower boiler drum, where it is de-superheated, and then passed back into the same main, on its way to the test bed.

Air for combustion provided by a forced draught fan is passed through the

envelope casing of the combustion chambers to provide a measure of pre-heat, and at the same time cool the casing. An induced draught fan deals with the gases from the boiler and discharges them to a stack 125 ft. high. By-pass is arranged for light load work. This fan has sufficient capacity for a second boiler when installed, and flues are arranged accordingly.

Sufficient economiser capacity is incorporated to give protection to the boiler, but no attempt has been made to obtain a high degree of efficiency as the unit is for test work only. Steam is supplied to the test beds through 6 in. bore piping.

Fig. 6.—Part of the exhaust steam mains in the test bed.

FEED WATER SERVICES.

Condensate is returned from the test beds to the boiler plant, where it is passed through two heaters, one fed with exhaust steam at 10 lb. per sq. in. and the other with live steam at 200 lb. per sq. in. The latter unit is brought into use automatically when the exhaust steam available is insufficient to raise the feed temperature to 200 deg. F.

The feed water is then passed to a Neckar de-aerator supplied by the Neckar Water Softening Co. Ltd. This is of the vertical type so that a pressure is maintained on the feed pump suction by the static head of water in the vessel.

Two Weir reciprocating feed pumps (one a standby) supply the feed water to the boiler. Steam of low superheat is taken from the top boiler drum and reduced to 200 lb. per sq. in. to supply the feed pumps, de-aerator, live steam heater, and oil unit. The exhaust from the feed pumps, de-aerator and oil fuel pump is taken to a common exhaust main at 10 lb. per sq. in., which in turn supplies steam for feed heating, and oil fuel heating in the tanks.

Any make-up water required is provided by a Neckar Monobed de-ionisation plant which deals with 250 gal. per hr.

The water is finally treated before entering the boiler by the addition of a small dose of caustic soda to render it alkaline, and raise the pH value to about 10 ; also, sodium sulphite is added to maintain the sulphate-carbonate ratio.

FUEL OIL SUPPLY.

Fuel oil, up to 1,500 seconds viscosity Redwood 1, is stored in an uninsulated tank of 300-ton capacity outside the boiler house. Two insulated storage tanks for fuel oil are installed inside the boiler house, each having a capacity of 14 tons. These two tanks provide sufficient oil storage for any test of normal duration. Exhaust steam, thermostatically controlled, is used for maintaining the oil temperature.

The oil fuel pumping and heating unit for feeding oil to the burners is of the dual type, with one steam-driven and one electric pump. Reducing valves control the pressure of oil to each set of burners.

While steam for the auxiliaries is taken normally from the top boiler drum, it can also be supplied from the works main boilers at 200 lb. per sq. in. pressure. This arrangement simplifies conditions for starting up, and at the same time can be used to increase the effective output from the test boiler.

Instruments are provided to show the temperature of feed water at all stages, fuel oil, flue gas, and final steam temperature. Steam flow to the test beds is both indicated and integrated. Draught gauges indicate the draught conditions at all stages. Provision has been made for installing an independently-fired superheater to raise the temperature of steam for the test beds to 1,060 deg. F.

CONDENSER.

The test beds are arranged with ample exhaust steam mains, comprising 4 ft. dia. pipes from each turbine exhaust running into a 4 ft. 6 in. dia. main trunking of ribbed construction for strength (fig. 6). By this means the steam is taken to a 4,000 sq. ft. surface condenser supplied by Worthington Simpson Ltd., to deal with 48,000 lb. of steam per hour, the condensate being returned to the boiler plant. A vacuum of 28 in. Hg is provided from a two-stage ejector supplied with steam at 200 lb. per sq. in. Provision is also made for direct injection of condensate into the exhaust main, should the exhaust steam contain any condition of superheat.

Water is circulated through the condenser by means of a centrifugal pump having a capacity up to 2,800 gal. per min. This water is taken from a concrete reservoir, to which it can be returned for idle condi-

tions of test. In running conditions the water is passed through either of two 18 in. dia. mains to the river.

The water in the reservoir is replenished from one or more of three wells in the factory, from which ample water is available at a temperature of 55 deg. F. A further well in the test beds provides cooling water for items such as compressors and other equipment under test. This supply is taken round the test beds through separate mains and discharged to one or other of the river mains.

LUBRICATION.

Two lubricating oil tanks, each having a capacity of 1,000 gal., can be used independently, or as one unit, to provide oil for the machines under test. These are coupled by a common suction main equipped with standard oil pumps. Provision is made for connecting the pumps of machines under test to this suction main if required.

Three oil coolers are provided in the test beds and the cooled oil is returned to a common main feeding the two oil tanks. From the common oil suction line, oil can be pumped to large oil storage tanks outside the shop, where it is treated in a Hopkinson centrifugal unit before test. Water for oil cooling is provided from the works service water supply at 75 lb. per sq. in. pressure, and discharged to the concrete reservoir for circulating water outside the building. This service water can be used for any other special auxiliaries.

MACHINES ON PIT AT OPENING.

To mark the official opening of the new shop, Lord Citrine unveiled a commemorative plaque and started up a 11,215 h.p. turbine which was on the bed for adjustment of governing valve and auxiliaries preparatory to being coupled to a 90,000 c.f.m. blower for a closed circuit air volume test. The complete turbo-blower (fig. 7) is the first of two 90,000 c.f.m. units being supplied for the power station of the new works of Colvilles Ltd. at Ravenscraig, Motherwell, where the G.E.C. is the main contractor for the power installation. In addition to the two turbo-blowers, the Company is supplying three 10 MW turbo-alternators and two turbo-driven water-circulating pumps for the first stage of the power station scheme.

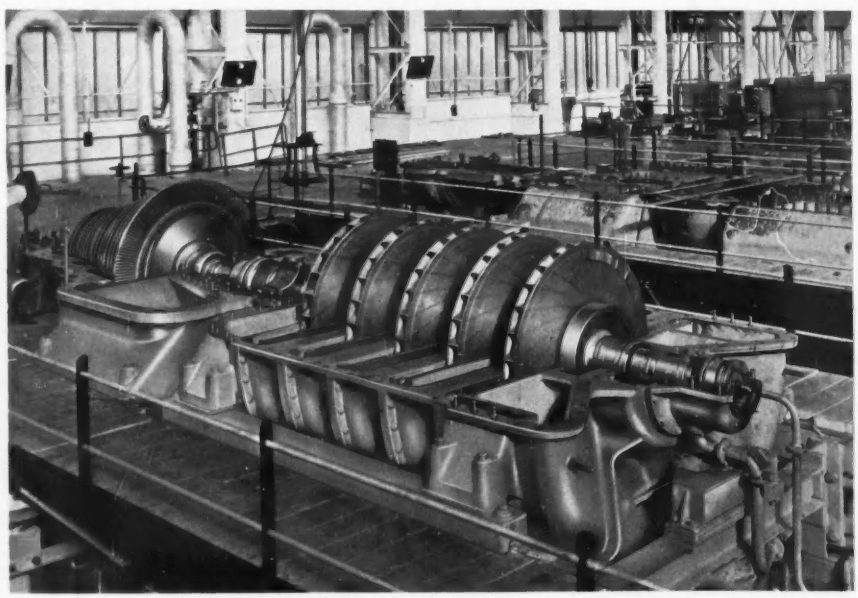

Fig. 7.—One of the turbo-blowers for Colvilles Ltd. in the new shop.

The Company's comprehensive contract for this project includes buildings, cooling towers, boilers, transformers, switchgear, lighting and all accessories. When installed, the Colvilles blower turbines will operate at 400 p.s.i.g., 800 deg. F., giving an output from the blower of 90,000 c.f.m. of air at 32 p.s.i.g. Speed will be 2,310/2,700 r.p.m. These machines are similar to the units of the 350,000 h.p. air compressor plant for which the Company recently received a unique order from the Ministry of Works.

Two turbines for G.E.C. turbo-alternator plant in course of supply to C.E.A. power stations were also on the bed. One of these was the sixth 60 MW machine for Uskmouth, where the G.E.C. is the main contractor for the complete turbo-alternator, condensing and feed heating plant, and for the main

transformers. The turbines operate with steam conditions of 900 p.s.i.g., 900 deg. F. and vacuum of 28·9 in. Hg (30 in. barometer).

The other turbine on the bed was the fourth of five 30 MW, 3,000 r.p.m. turbo-alternators being supplied by the G.E.C. to the Huncoat generating station of the C.E.A. Steam conditions of the turbine are 600 p.s.i.g., 850 deg. F. and vacuum 28·6 Hg (30 in. barometer).

Fig. 8.—Switch room in the new shop.

ELECTRICAL SERVICES.

A three-phase supply is brought into the switch room of the new shop (fig. 8) from the 2,850 volt works ring main circuit. Two 250 kVA external transformers are supplied to step the supply down to 415 volts. The low-voltage supply is brought into a six-panel board for distribution throughout the shop. A D.C. supply is obtained from the works rectifiers. Switchgear on all the shop distribution boards is colour coded as follows :—

Green	415 volts A.C.
Red	500 volts D.C.
Grey	250 volts D.C.

A 127 kVA power factor correction capacitor assembly is housed in the switchgear room.

LIGHTING, HEATING AND VENTILATION.

Lighting in the main shop comes from a combination of mercury and fluorescent sources. Three rows of 1 kW mercury lamps in high bay fittings are supported on brackets from the roof trusses at 20 ft. centres

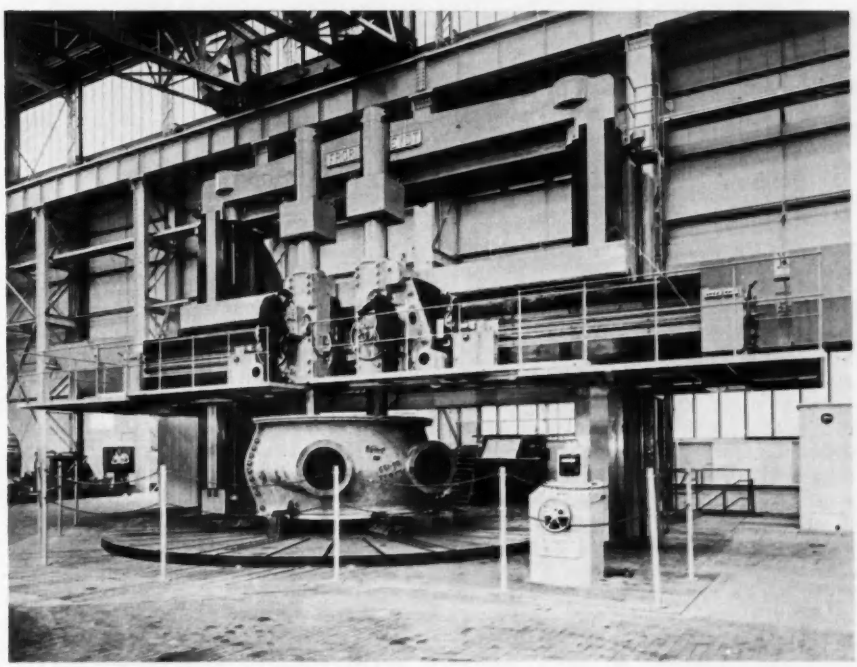

Fig. 9.—Machining a turbine centre exhaust casing on the 26 ft. vertical boring and turning mill.

longitudinally and with 37 ft. between the rows. The height above floor level is 58 ft. Walkways give access to all fittings, and the boxes housing the control gear are attached to the handrails.

A row of angle type twin tube fluorescent fittings with louvres runs round all four walls of the main shop 30 ft. above the floor. Fittings are mounted end to end except where spacing is necessitated by the structural design. The average service illumination is 20 lumens per sq. ft., and the proportion of fluorescent to mercury sources ensures a pleasing quality of light.

In the machine tool annexe the fittings are a combined mercury and tungsten type, each housing one 400 W mercury and one 750 W tungsten lamp. This combination also provides lighting of an acceptable colour, assisted by a reflector designed to give similar light distribution from both sources and thus obtain effective colour blending.

Heating is by a hot water system with Electroflo electronic control of water temperature, using water heated by steam supplied at 200 lb. per sq. in. pressure from the main boiler plant. The water is pump-circulated through 19 downstream dual-flow heaters with fans for circulation of air. In addition radiant heating panels are mounted at 13 ft. level round the shop. Further unit heaters mounted in pairs above the doors are arranged to be switched on automatically when the doors are opened in cold weather.

Natural ventilation is provided by roof cowls.

The shop is liberally provided with natural lighting, both by windows and continuous glazing in the roof. All high-level windows can be motor-operated from remote control push button stations at floor level. Local control push buttons are fitted at window level.

Every effort has been made in planning facilities to ensure working conditions which will promote efficiency, and enable the new shop to make a contribution worthy of the advanced standards of its technical equipment to the expanding demands for heavy electrical power plant.

MACHINE TOOLS.

The shop is fully equipped to undertake the turning, planing, boring and drilling of large castings and machining of smaller parts. Rotor discs are machined in the shop, but the blades are fitted and the rotors assembled complete, and balanced, in one of the other turbine shops, whence they are delivered to the new shop for building into the machines.

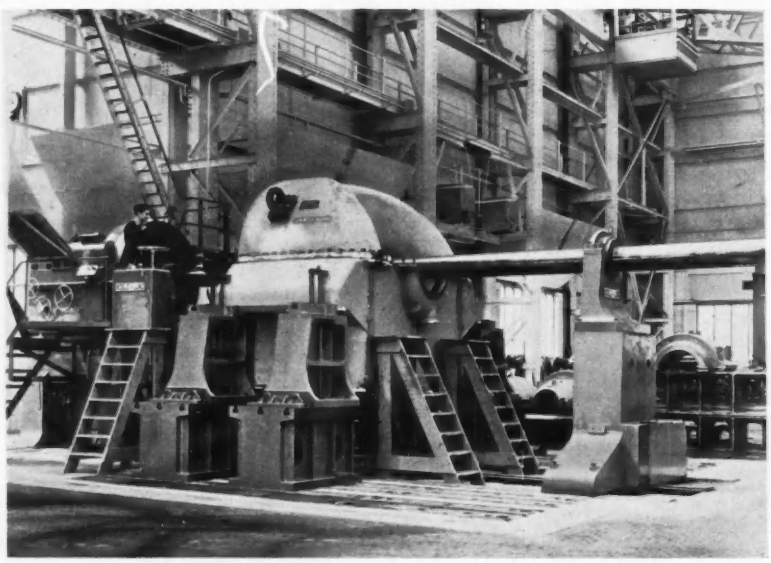

Fig. 10.—Boring bearing-ways in a turbine low-pressure casing.

Most of the machine tools are housed in the annexe, but several of the larger units are accommodated in the main shop. A Froriep 26 ft. vertical boring and turning mill installed for work on the largest parts, such as turbine exhaust casings, is one of the largest of its kind in the country. This machine (fig. 9) was among those acquired from Germany after the war as reparations. The table, made in three sections, will take a total load of 200 tons, and is 25 ft. 9 in. in diameter. A special feature is the maximum height under the tool, which is 13 ft. 11½ in.

The main motor is a 500 volt D.C. machine of 173 h.p. and the speed range of the mill is from 0·2 to 6·7 r.p.m. Auxiliary motors comprise two of 7¾ h.p. for rapid traverse of the slides and two of the same rating for rapid traverse of the rams ; one 33½ h.p.

motor for raising and lowering the cross rail ; a 12½ h.p. motor for mechanical clamping of the rail ; and a 1 h.p. oil pump motor. All auxiliary motors are 415 volts A.C.

A Craven 12 ft. vertical boring and turning mill with 5 ft. 6 in. ram traverse will be installed in the main shop for machining high pressure steam casings, and arranged to admit 10 ft. 6 in. under the tool holder. The main driving motor is of 50 h.p. A 6 ft. vertical boring and turning mill of Craven manufacture is also provided, and a similar machine in box. The main driving motor is of 20 h.p., and auxiliary 7½ h.p. motors are provided for rapid power traverse of the headstock and boring steadies, and rapid adjustment of the outer steady.

The shop is to be equipped later this year with a Craven 45 ft. stroke planer for planing turbine casings, etc., with measurements of 15 ft. between uprights and 10 ft. 6 in. under the tool. This machine has two tool boxes on the cross slide and one side tool box on each upright. Electro-magnetic tool-lifting is incorporated to raise the tools from the work on the

Fig. 11.—A turbine high-pressure casing in the horizontal boring and tapping machine.

the annexe will be used for taper turning rotor discs before the blades are fitted.

An Asquith 12 ft. 6 in. radial drilling machine in the main shop is employed on drilling bolt holes in all casings and has been adapted to take work of over 10 ft. 6 in. under the spindle.

For boring turbine cylinders, the shop is also equipped with a Noble & Lund machine (fig. 10) taking a 12 in. boring bar. Height from 23 ft. 9 in. by 10 ft. work bedplate to the centre line is 9 ft., and the distance between steadies 20 ft. Sixteen rates of feed are provided by a drive from a 3 h.p. variable-speed motor through a change-speed gear-return stroke. The table is driven through spiral gears.

The main driving motor will be a 120 h.p. variable speed machine supplied from a Ward-Leonard set, having a speed range of 350/700 r.p.m. Cutting and return speeds will be 20 to 120 f.p.m. in high gear, and 12½ to 75 f.p.m. in low gear.

Both saddles of the machine are adapted for cross planing and driven by a separate 25 h.p. reversing motor. A 15 h.p. motor drives the patented electric feed gear, and the same motor is used for quick traverse of the tool boxes. Two small pump motors are fitted for lubrication.

Also in the main shop is a Kitchen & Wade horizontal boring and tapping machine (fig. 11) with a 4 in. spindle, having 36 speeds and 18 rates of feed. The machine is driven by a 10 h.p. motor.

ANNEXE EQUIPMENT.

Machine tools accommodated in the annexe (fig. 12) comprise internal and external grinding machines, lathes, horizontal and vertical boring, facing and turning machines, and a slotting machine.

The grinding machines are a Churchill model A.C. 48 in. universal internal grinder, with 24 in. swing over the table, for grinding valve bodies and a Churchill model CW 12 in. by 72 in. plain grinder for grinding governor shafts. Both machines have hydraulic table traverse.

Two Swift V5 36 in. centre lathes admit respectively 10 ft. 6 in. and 21 ft. between centres. Eighteen speeds between 4 and 230 r.p.m. are available, together with normal and coarse rates of feed. The machines have 20 h.p. driving motors. In addition three small Swift lathes with 12½ h.p. motors and 18 speeds between 9 and 420 r.p.m. are installed for detail work.

One large Swift lathe is to be provided for cutting high-pressure turbine shafts from the solid. The length between centres is 18 ft., and the headstock has been raised specially by 7½ in. for the work on which it is to be employed.

A Richards No. 4 Electrobore horizontal boring and facing machine, with traversing spindle and arranged for screw cutting, is installed for work on valve bodies and small parts. Maximum height from the 4 ft. by 4 ft. revolving table to the spindle is 38½ in.

Keyways in turbine rotor discs are cut on a 16 in. Ormerod slotting machine with self-acting longitudinal traverse and circular power feed.

Another Craven 6 ft. vertical boring and turning mill similar to the one in the main shop is installed in the annexe, together with two 10 ft. Craven machines, driven by 40 h.p. motors.

The annexe equipment is completed by three Mitchell double-grinders for general maintenance of tools and an Asquith 5 ft. 9 in. portable drill.

Fig. 12.—Machine tools in the annexe.

The EW54 Germanium Junction Rectifier

By R. D. KNOTT, M.Sc., and J. I. MISSEN, M.Sc., A.R.C.S.
Research Laboratories.

This article discusses the basic physical concepts relating to semi-conductor alloy-junction rectifiers and their application to the EW54 germanium p-n junction diode. The manufacture, electrical characteristics and performance of this diode are discussed and possible fields of application summarised. The efficiency of this type of rectifier is extremely high, which makes its use attractive in the higher power range with comparatively simple cooling systems.

INTRODUCTION.

DURING the past few years a class of materials known as semi-conductors has become the focus of much research and development in the electrical industry. In particular a range of new devices is being made from germanium, which at the present time is the most widely used material. Most of this research and development has sprung from the invention of a semi-conductor amplifying device, known as the transistor, but the *p-n* junction rectifier is another development likely to prove of almost equal importance.

The EW54 is one example of such a rectifier made by the so-called alloy process. It has been designed for operation at medium voltages and currents. Thus, using simple fins of the type shown in fig. 1, four EW54 rectifiers can handle an output of 50 volts at 12 amp at an ambient temperature of 35 deg. C. A particular feature is their very high rectification efficiency, values of 95 per cent. and upwards being obtainable. These efficiencies result from the very low resistance of the rectifier in its conducting direction and its comparatively high resistance in the reverse direction.

The ratings of the rectifier are partly determined by its internal temperature measured at the *p-n* junction itself. Thus, if more elaborate cooling arrangements are used, the ratings, in particular the value of the maximum output current, can be substantially increased.

INTRODUCTORY PHYSICS.

Semi-conductors are solids having electrical characteristics intermediate between those of metals and insulators. Thus the resistance of a unit volume of a semi-conductor is about a million times that of a metal and a millionth of that of an insulator. Germanium in its pure form is such a material and is of considerable practical interest because it can be used to produce an important range of new electronic devices. One of these is the *p-n* junction diode.

Before discussing the structure of a crystal of germanium, it may be useful to consider a molecule of hydrogen. Each of the two atoms forming the molecule has one proton and one electron. The proton is about 2,000 times as heavy as the electron and is a relatively immobile particle about which the electron moves in certain permitted ways, or quantum states. Further, mathematical analysis shows that, in the case of an isolated atom, the electronic charge is distributed as a diffuse sphere about the proton. When the two atoms are brought close together the two electronic clouds become modified to give an extra accumulation of charge between the two protons. This accumulated charge constitutes an electron-pair bond holding the two atoms together in the hydrogen molecule.

Returning to germanium, this element has an atomic number of 32. This number is equal to the charge on the atomic nucleus measured in units of electronic charge, so that a neutral germanium atom has a nuclear charge of $+32e$ surrounded by 32 electrons each of charge $-e$. Of these 32 electrons

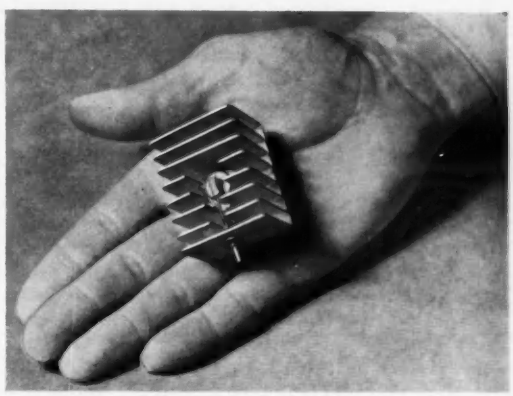

Fig. 1.—The EW54 diode and convection cooling fins showing comparative size.

only four, the so-called valence electrons, are able to enter into chemical reactions, the remainder being closely bound to the nucleus to give a stable "core" with a net charge of $+4e$. This core can be regarded as completely inactive so far as electronic process in chemical reactions and in semi-conductors is concerned.

Each germanium atom forms electron-pair bonds with four other germanium atoms so that all its valence electrons are used up. This condition is completely satisfied in the diamond crystal lattice structure, illustrated in fig. 2, in which a typical atom is surrounded by four neighbours placed at the corners of a regular tetrahedron.

We can now see intuitively why the electrical conductivity of germanium is very much less than

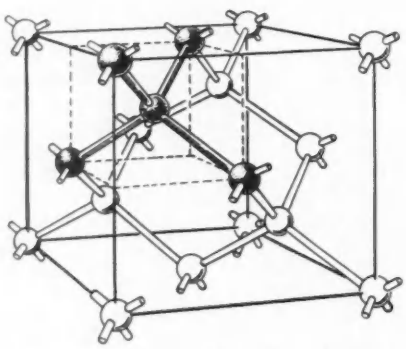

Fig. 2.—The crystal structure of germanium showing how each atom forms four bonds with its nearest neighbours.

that of a typical metal. The metallic bond may be described as a gas of free electrons producing a uniform cloud of negative charge in which the positive ions of the metal float. In germanium, however, the electrons may be considered as the structural elements which hold the crystal together. In the perfect crystal every electron would be tightly bound and thus unable to enter into the conduction processes. Conductivity can be produced, however, in a number of ways, all of which involve the destruction of the perfect valence bond structure. For example, a photon of light falling on the crystal can give up its energy to an electron which is ejected from its bond in the crystal lattice. This ejected electron constitutes a localised negative charge in the crystal as shown in fig. 3, since it represents an excess over and above that required to complete the bond structure in its neighbourhood. It is referred to as an "excess electron" and it migrates in a random manner in the crystal under the influence of thermal agitation. If an electric field is applied, it acquires a systematic drift which constitutes an electric current.

The "hole" left in the bond when the ejected electron moves away constitutes a net, localised, positive charge which can move at random in the crystal by a reciprocal motion of electrons in the valence bonds, as shown in fig. 3. Under the influence of an electric field it also acquires a systematic drift and contributes to the current.

The electrons and holes drift in opposite directions in the applied field; the electrons, being negative charges, drift in opposition to the field, but the electric current produced is, of course, in the direction of the field. In the case of the holes, the reciprocal electron motion is in opposition to the field and, as a consequence, the holes drift in the direction of the field. Further, since their charge is positive, they add to the electron current. This is shown pictorially in fig. 4.

On removal of the light source in the above example, the photoconductivity dies away and the crystal returns to the normal state. This is brought about by the recombination of the excess electrons and holes, for, if an electron drops into a hole, both the hole and

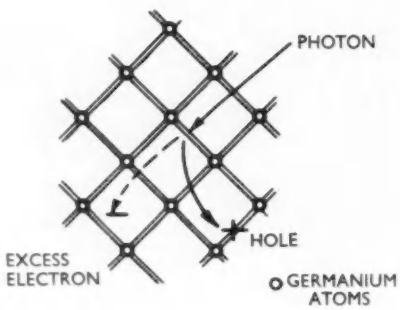

Fig. 3.—Production of a hole-electron pair by a photon. (The figure represents a plane diagram of the diamond lattice.)

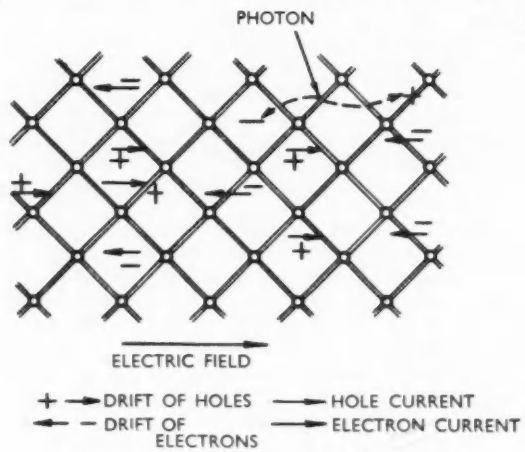

Fig. 4.—Drift of holes and excess electrons in an electric field.

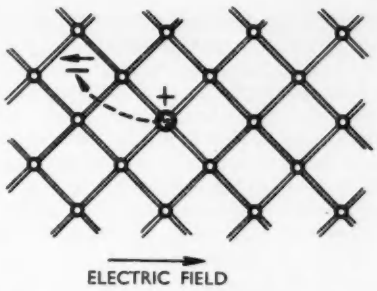

Fig. 5(a).—Excess electron or "n"-type conductivity in germanium containing arsenic.

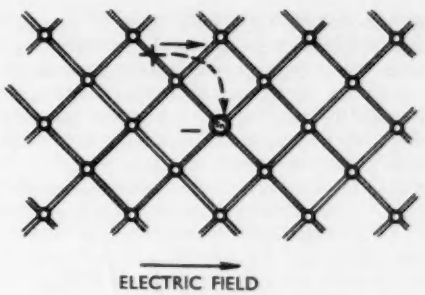

Fig. 5(b).—Hole or "p"-type conductivity in germanium containing indium.

the electron disappear and the bond structure is completed.

There is obviously an important distinction between the behaviour of electrons which have been excited out of the valence bond structure and those remaining in it. According to theory, the electrons in the valence bonds occupy a set of energy levels covering an allowed band. All these levels are occupied in the ideal crystal, and the band is referred to as the " filled " or " valence " band. It is impossible for an electron to have an energy greater than that of the highest level in the valence band unless it is given a sufficiently large increment of energy so that it may become a free electron. The electrons in these free states may also have various energies and give rise to a second energy level scheme known as the " conduction band." The valence and conduction bands are separated by a region of forbidden energies for which there are no energy levels in the crystal. This gap is some 0·75 electron volts in germanium.

It should be emphasised that at temperatures other than absolute zero, some electrons will be excited to the conduction band, leaving a corresponding number of holes in the valence band. Conduction can now occur by electrons in the conduction band and by holes, due to the presence of the vacant levels in the valence band. This form of conductivity by equal numbers of electron-hole pairs is referred to as intrinsic conductivity and increases rapidly with temperature.

Let us now consider the effect of adding to the germanium a trace of an impurity element, such as arsenic, which has five valence electrons surrounding a core having a charge of $+5e$. Such an atom will displace one of the germanium atoms from its site in the crystal lattice and form four electron-pair bonds with the neighbouring germanium atoms, thus using four of its five valence electrons. The extra electron is unable to fit into these bonds and is thus free to move about the crystal, where it constitutes a mobile, localised negative charge. The arsenic atom is, however, an immobile localised positive charge, since its core, with a charge $+5$ units, is not neutralised by its share in the covalent bonds. Its net charge just balances that of the excess electron and does not disturb the overall electrical neutrality of the crystal. The extra electrons are attracted to the arsenic atoms and, at a low temperature, they are bound together. At room temperature, however, thermal agitation frees the electrons from practically all the impurity atoms. The conductivity of the germanium containing such a " donor " impurity is thus due to excess electrons and is referred to as *n*-type.

Similarly, if an element such as indium, which has three valence electrons, is present as an impurity, it cannot complete the valence bond structure around it. The vacancy in one of the bonds can be filled by an electron from an adjacent bond and the hole can migrate away. The indium atom thus becomes an immobile, localised negative charge. Because of the symmetry between the behaviour of electrons and holes, we can describe this situation by saying that the negative indium atom attracts the positively charged hole but then, at room temperature, thermal agitation frees the latter so that it is free to contribute to the conductivity of the crystal. Conduction is here referred to as *p*-type and the impurity atoms as acceptors.

N- and *p*-type conductivity is illustrated in fig. 5(a) and (b) and the several terms and other features already discussed are summarised in Table 1.

TABLE 1.

Conductivity type :	*n*-type	*p*-type
Conduction by :	Excess electrons	Holes
Energy band in which carrier moves :	Conduction band	Full or valence band
Sign of carrier :	Negative	Positive
Valence of impurity atom :	5	3
Name of impurity atom :	Donor	Acceptor
Typical impurities :	Phosphorus P Arsenic As Antimony Sb	Boron B Aluminium Al Indium In Gallium Ga

THEORY OF A *P-N* JUNCTION.

It is a well-established fact that the intimate junction between *n*- and *p*-type germanium forms a rectifying barrier as shown in fig. 6. If a positive potential is applied to the *n*-material and a negative potential to the *p*-material, the electrons and holes are attracted in opposite directions towards the positive and negative connections respectively. A transition region is therefore created which contains very few current carriers. This constitutes a barrier layer and is, in effect, an insulator. Its width increases both with the resistivity of the material and with the applied potential. In practice it lies in the range 10^{-2} to 10^{-5} cm. Reversal of the polarity produces an attraction between the two carrier types so that the barrier layer becomes a recombination region, a condition providing low resistance to current flow.

Quantitatively, it may be shown[1] that the net hole current across the junction is given by :

$$I_p = I_{pR} \left(\text{Exp } \frac{eV}{kT} - 1\right), \qquad (1)$$

where V is the voltage (positive values of V being forward) applied across the junction, e is the electronic

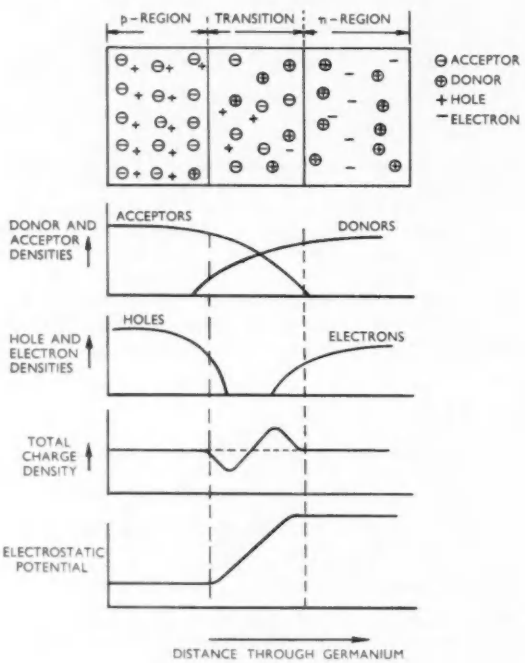

Fig. 6.—The p-n junction.

charge and kT is thermal energy. The value of I_{pR} depends only on the *n*-type material and is proportional to the hole concentration in this region. Further, for a semi-conductor in equilibrium the product of the electron and hole densities is constant so that, if the *n*-region has a high electron concentration, it has a low hole concentration and I_{pR} is small. A similar equation applies for the electron current I_n in terms of I_{nR}.

For the alloy type junctions to be considered in connection with the EW54 rectifier, the concentration of holes in the *p*-region is much greater than that of electrons in the *n*-region so that, by the above reasoning, I_{nR} will be very small compared with I_{pR} and in the forward direction the current flows across the junction mainly as holes.

PRACTICAL RECTIFIER DESIGN.

One of the several practical methods for forming a *p-n* junction, and that used in the production of the EW54, is known as the alloy process. It involves the formation of a *p*-type region, of suitable area, on a piece of *n*-type germanium by recrystallisation from an indium-germanium alloy produced *in situ*. The *p*-layer formed in this way has a low resistivity and is a crystallographic continuation of the original *n*-type material.

Several general features, both in the design of the *p-n* junction itself, and in the subsequent completion of the rectifier, must be given careful consideration. Firstly, the area of the *p-n* junction must be sufficiently large to pass the proposed peak forward current, a practical design figure being approximately 100 amperes per square centimetre, and the resistivity of *n*-type germanium must be high enough to withstand the peak inverse voltage applied, a point which is discussed in more detail under " Electrical Characteristics." From the aspect of a completed rectifier, good ohmic, that is non-rectifying, contacts must be made both to the *n*- and *p*-regions, and at least one of them must be coupled to a heat sink. Finally, the device must be hermetically sealed in a container to protect the junction from the adverse effects of moisture.

THE EW54 RECTIFIER.

In the EW54 rectifier, the *p-n* junction is formed on a wafer of single crystal germanium, some 6 mm. square and 0·4 mm. thick, having a resistivity of about 10 ohm.cm. These wafers are cut from the grown crystal using a diamond-impregnated saw. They are then carefully lapped and chemically etched to give the required thickness and surface condition. These treatments remove the damage to the germanium crystal lattice which is introduced by sawing, and their control is of primary importance in constructing devices which will pass low reverse currents.

In the next process, the *p-n* junction is formed on the upper surface of the wafer while the lower surface is soldered to a copper block which acts both as a heat sink and as a connection to the *n*-region. To do this, units are jigged with the germanium resting on the top of the tinned copper block and with an accurately controlled quantity of indium located centrally on the upper surface of the germanium wafer. These units are taken through a furnacing cycle in a hydrogen atmosphere. As the temperature is raised the indium first

melts and then, with continued rise of temperature, alloys progressively with the germanium. The quantity of germanium taken into solution, or the depth of penetration of the alloy front, is governed by the mass of indium present and by the maximum furnacing temperature. Approximately 100 milligrammes of indium and a furnace temperature of some 500 deg. C., combine to give the required penetration in the present application. On cooling, the germanium recrystallises from solution as a crystallographic continuation of the *n*-type material, sufficient indium being present in this recrystallised layer to make it *p*-type with a resistivity of a few milliohm centi-

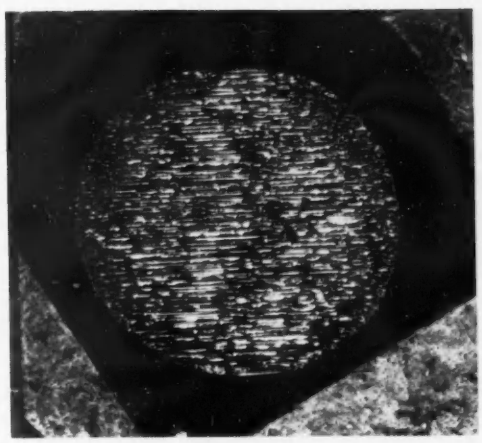

Fig. 7.—Plan view of the germanium wafer with the alloy indium bead dissolved away. The " ridged-roof " structure is typical of germanium cut perpendicular to the 110 direction.

metres. During the heating the molten solder wets the germanium and forms a good non-rectifying connection between the *n*-region and the copper block.

Not all the dissolved germanium recrystallises to form the *p*-layer. Some forms *p*-type germanium crystallites in the body of the molten indium, which float to the surface and play no part in the *p-n* junction mechanism. Their formation is kept to a minimum to ensure a thick, uniform *p*-layer—a condition which is essential for good rectifier performance. The uniform nature of the recrystallised layer is demonstrated in fig. 7, which is a plan view of this layer after the indium has been removed. The " ridged-roof " structure is typical of that formed on germanium cut perpendicular to the 110 direction.

Another important feature in the manufacture of *p-n* junction rectifiers is the profile of the junction itself. This should be as nearly planar as possible for, if a greater alloying depth occurs at isolated points, then the base thickness must be increased to avoid short circuit failures. This increases the power losses in the device and reduces its efficiency. Conversely, taking the other extreme, an island of unalloyed germanium might be left standing proud of the recrystallised region. This will obviously reduce the junction area and consequently its current-handling capacity. It may also produce a short circuit. An approach to the ideal junction profile clearly depends on achieving a uniform alloying rate over the whole junction area. The photomicrograph, fig. 8, indicates how nearly this is met in the EW54 by careful control of assembly and processing. This junction was etched preferentially to make the *p-n* transition clearly visible.

It will also be noted from fig. 8 that a considerable mass of indium is used to form the junction. This is governed primarily by the required alloy penetration but it incidentally provides a convenient method for making an electrical connection to the *p*-layer. This is effected by using the indium itself to solder a lead into the bead during the junction-forming process.

After junction-forming, it is customary to carry out a chemical etching process to remove traces of indium and other contaminants from the surface of the germanium and, in particular, from the region where the *p-n* interface breaks the surface of the base material (fig. 8). A trace of indium over this region acts as a resistance in parallel with the junction, resulting in a low reverse impedance.

As mentioned above, the level of both the reverse current and the " breakdown " voltage of the rectifier are severely impaired by very small traces of moisture. It is thus essential to enclose the rectifying unit in an hermetically sealed container, filled with a dry gas. In this connection, the cold pressure welding technique, developed some time ago at the Research Laboratories of the G.E.C., has several noteworthy advantages over other methods and has been applied to the EW54. Basically, the process entails the pressing together of two metal components whose mating surfaces have been prepared by scratch brushing, or by other suitable treatments. The weld is made at normal room temperature and is effective with several metals including copper and aluminium.

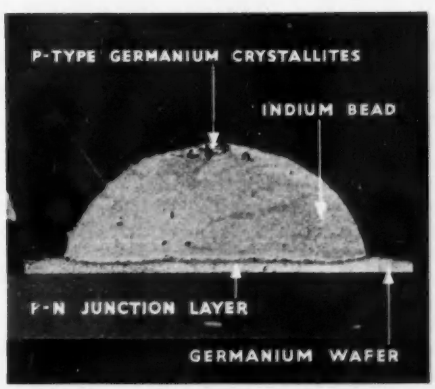

Fig. 8.—Cross-section of the germanium wafer and alloy indium bead showing penetration of the junction layer into the wafer.

The two primary factors controlling the quality of the weld are the state of the surfaces to be welded,

Fig. 9.—EW54 germanium p-n junction diode.

and the percentage thickness reduction of each member during welding, which must exceed a minimum value characteristic of the particular metal. The advantages of this technique over other alternatives, such as soldering and resistance or arc welding, are that a mechanically strong hermetic seal can be made without the use of heat or fluxes, either of which may give rise to contaminating vapours which impair the characteristics of the rectifier.

Copper was selected for the container of the EW54 from practical considerations, and the cold weld seal is made between mating flanges on the copper block and a top cap. To make the weld, a pressure of several tons is applied with the device located between two ring punches. The lead from the indium bead passes out of the container through a metal tube glass-sealed into the copper cap. A cold weld "pinch-off" seal is made between this tube and the lead before finally fixing a flexible connector with soft solder. The two cold welding operations are carried out in a dry inert atmosphere. The completed EW54 rectifier is shown full size in fig. 9.

ELECTRICAL CHARACTERISTICS OF THE EW54 RECTIFIER.

The characteristics of an EW54 rectifier at a temperature of some 20 deg. C. are shown in fig. 10. Typically, a forward current of 8 amp at +0·5 volts is achieved and the forward slope resistance is some 0·02 ohms over the linear region of the characteristic. The reverse characteristic deviates from the theoretical form given in equation (1), the current increasing slowly beyond the saturation value before breakdown is approached at about 140 volts.

The "breakdown," or voltage-limiting, region of the reverse characteristic merits a somewhat more detailed consideration. The effect was originally attributed to internal field emission in the barrier region. This explanation, which arose from an extension of Zener's theory of dielectric breakdown,[2, 3] led to the commonly used term of "Zener Breakdown" for the effect. More recent work, however, has shown that, for the range of germanium resistivities used in practice, the effect is brought about by an avalanche mechanism. This is built up by the multiplication of the carriers which constitute the reverse current when they pass through the barrier field [4, 5].

On the basis of the later theory, a breakdown voltage of 300-400 volts is predicted for junctions formed on 10 ohm.cm. germanium but, although such values may be achieved consistently under experimental conditions, the full working voltage has not yet been attained in a device of the EW54 type. The premature breakdown which is observed is known to be caused by very thin, and possibly by mono-molecular layers, of adsorbed water on the germanium surface. It is expected that improvements in manufacturing techniques, at present being introduced, will result in an increase of some 100 volts in the observed breakdown voltage. High working voltage rectifiers are also planned with breakdown voltages in the range 400-550 volts. These junctions are formed on high resistivity germanium.

The effect of temperature on the rectifier characteristics is to increase both the reverse and forward currents at specified voltages. This effect is shown for a typical rectifier in fig. 10. The reverse current change is by far the more important and, at a constant voltage, it increases exponentially with temperature

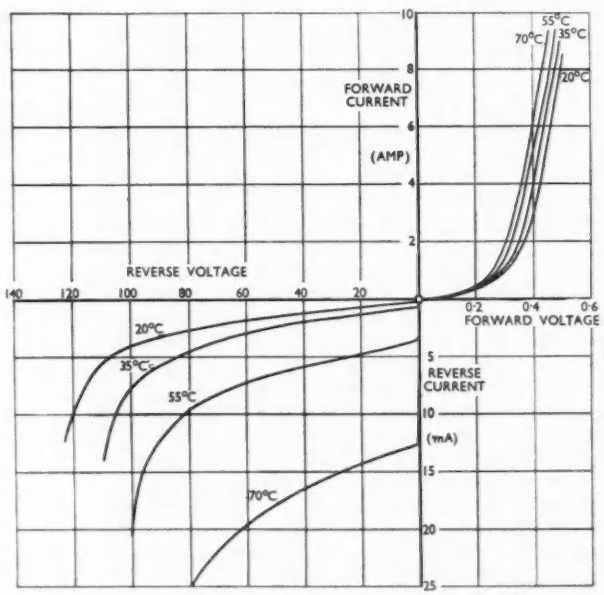

Fig. 10.—Static characteristics of the EW54 diode at various ambient temperatures showing the temperature dependence of the characteristics.

according to the empirical relationship :

$$I_T = I_o e^{\alpha T} \qquad (2)$$

where T is the temperature in degrees Centigrade and α and I_o are constants.

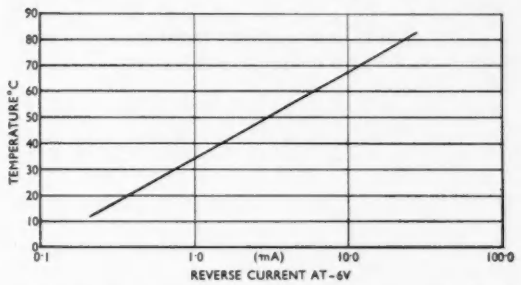

Fig. 11.—Reverse current at constant voltage against junction temperature. (Results are taken from fig. 10.)

METHODS OF ASSESSMENT OF RECTIFIER PERFORMANCE.

From the D.C. characteristics, fig. 10, it may be seen that the diode will withstand a peak inverse voltage of at least 100 volts at an ambient temperature of 20 deg. C., while the forward current increases rapidly with forward voltage above 0·3 volts and is typically 8 amp at 0·5 volts. With such a characteristic, the forward power dissipation in operation is much smaller than is the case with other types of rectifier so that the temperature rise is correspondingly lower. However, the lower forward dissipation is somewhat offset by the fact that the reverse current of a germanium diode is a function of temperature, as is shown in fig. 11. Operation of the diode at high temperature will result in an increased reverse power dissipation which in turn produces a higher internal temperature. The whole process can end in a condition known as " runaway," in which the internal temperature rises extremely rapidly and finally results in diode failure.

The maximum power rating for the diode is therefore determined by the junction temperature. An accurate method for determining the internal temperature is desirable, and the diode is convenient in this respect, in that it may be arranged to act as its own thermometer.

For values of reverse voltage greater than about 0·1 volt the term $\exp(-^{eV}/_{kT})$ in equation (1) is very much smaller than 1 and can be ignored. Thus I_p is now equal to I_{pR} and is substantially independent of reverse voltage. In practice, the reverse current does increase with reverse voltage but this change only becomes significant at high voltages. This current I_{pR} is highly dependent on temperature, the exact relationship being rather complicated. However, for the normal range of temperature over which the diode can be used, it is found that expression (2) provides an adequate representation. By taking natural logarithms the expression becomes

$$\log_e I_T = \alpha T + b \qquad (3)$$
$$(b = \log_e I_o)$$

Thus by plotting the logarithm of reverse current against temperature, a straight line law results (fig. 11) of slope α and intercept b. If any given diode is heated externally and the reverse current at constant voltage is measured as a function of temperature, α and b may be determined for the diode and thereafter the reverse current at constant voltage may be used to determine the junction temperature for the diode.

This method is found to be very convenient in practice ; a typical practical arrangement is shown in fig. 12 for single phase bridge operation, although the method is equally applicable to other circuit arrangements. To determine the diode internal temperature SW1 is operated, so that a reverse voltage of 6 volts is rapidly applied to the diode, the reverse current is measured, and hence the internal temperature obtained from the calibration curve. The thermal time constant of the diodes is sufficiently long (see (*g*) below) for no error to arise from the finite duration of the measurement.

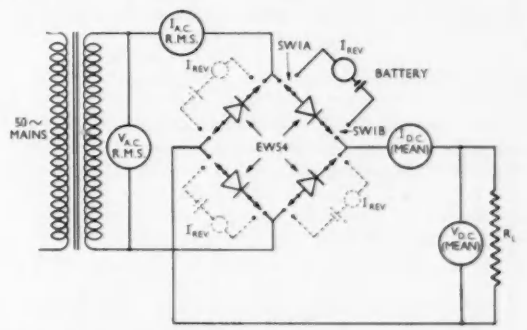

Fig. 12.—Method for measurement of junction temperature in operation (using fig. 11).

Initial experiments were carried out to determine the maximum internal temperature the diode can withstand for reliable operation. To establish maximum ratings for the diode in any given circuit arrangement the internal temperature was noted at various rectified currents for a number of D.C. output voltages. Hence a family of characteristics for the three variables—output voltage, output current and internal temperature—was obtained. From these results it was possible to determine the maximum output voltage and current ratings for a number of conditions of ambient temperature and diode internal temperature, as discussed later.

PERFORMANCE OF THE EW54.

(*a*) Design of Cooling Fins.

Although the EW54 diode is a highly efficient

rectifier it does dissipate some finite power which causes the temperature at the junction to increase. Since this temperature must not exceed a certain amount, the maximum power that can be handled by the rectifier depends very largely on the system used for cooling it. The work discussed in this article relates only to simple convection cooling systems. Clearly, by using forced air or liquid cooling, it is possible to operate at higher ratings than those discussed here.

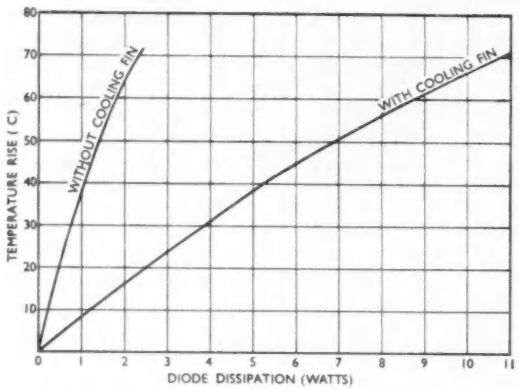

Fig. 13.—Curves showing the junction temperature rise for a given diode power dissipation (diode with and without cooling fins).

A number of simple cooling fin arrangements were investigated. One of the design targets was a 50 c/s full-wave bridge rectifier system to give an output of 50 volts at 12 amp at 35 deg. C. ambient temperature. Calculation and experiment showed that a power dissipation of approximately 5 watts per diode was involved. The cooling fins were then designed to keep the diodes within the maximum internal temperature rating. An approximate criterion of 1 watt dissipation per square inch per 100 deg. C. temperature rise was used. On this basis a fin approximately 16 sq. in. in area was necessary and it was felt that a multi-plate arrangement was more practical than a single plate.

Although many forms of multi-plate fins are possible, it was decided to use the channel type cooling system shown in fig. 1 as this had the merit of being cheap to produce and also provided mechanical protection for the glass-to-metal seal at the top end of the diode.

In the majority of experiments to assess its performance, the diode was fitted either with the channel cooling fins, or no cooling attachment whatsoever. Fig. 13 gives comparative results for the diode internal temperature against internal power dissipation.

(*b*) Operation into a Purely Resistive Load.

As this is the simplest case it is taken first. Referring to fig. 12 it will be seen that the input power is measured as the true power, while the output power is obtained as the product of mean voltage and mean current. A factor of $\left(\frac{\text{MEAN}}{\text{R.M.S.}}\right)^2 = 0{\cdot}81$ will be introduced in determining the efficiency as the ratio of $\frac{\text{output power}}{\text{input power}}$. By definition the maximum efficiency of any system, assuming a sine-wave input, is 81 per

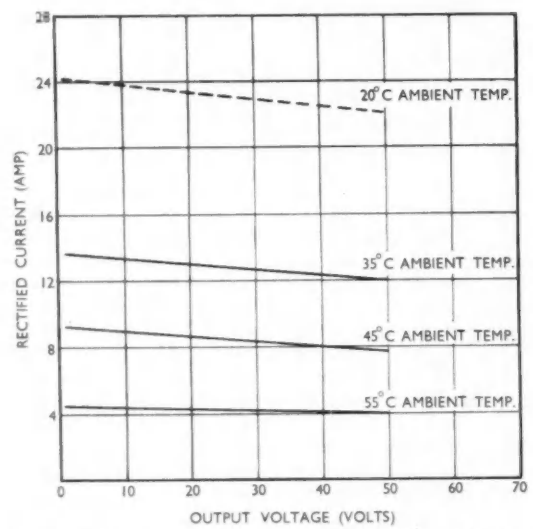

Fig. 14.—Maximum rectified current against mean D.C. output voltage for various ambient temperatures with bridge operation into a resistive load and EW54 diodes fitted with cooling fins.

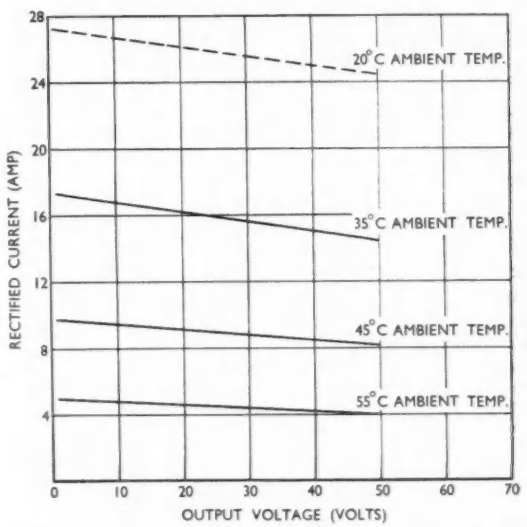

Fig. 15.—Maximum rectified current against mean D.C. output voltage for various ambient temperatures with bridge operation into a resistive load with smoothing choke and EW54 diodes fitted with cooling fins.

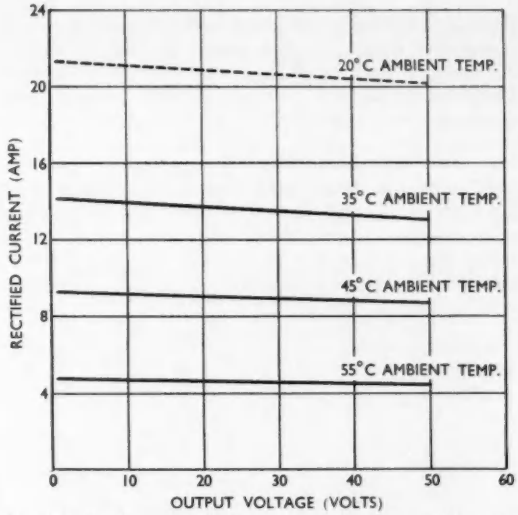

Fig. 16.—Maximum rectified current against mean D.C. output voltage for various ambient temperatures with bridge operation into a battery load and EW54 diodes fitted with cooling fins.

cent. A more realistic figure for overall efficiency may be obtained by noting the temperature rise of the rectifiers and hence their power dissipation. On subtracting this total diode dissipation from the input power to obtain the output power, the efficiency related to a 100 per cent. maximum may be calculated.

Using this latter definition, figures of over 95 per cent. efficiency are readily obtained. With channel cooling fins at an ambient temperature of 35 deg. C., a rectified current of 12 amp is obtainable with full-wave bridge or bi-phase connection and a resistive load ; typical rating curves are shown in fig. 14. In the case of bridge operation the peak inverse voltage per diode is the peak value of the applied A.C. voltage, while for bi-phase operation the peak inverse voltage is double this value. Hence for a given reverse voltage rating per diode, the bridge circuit is able to

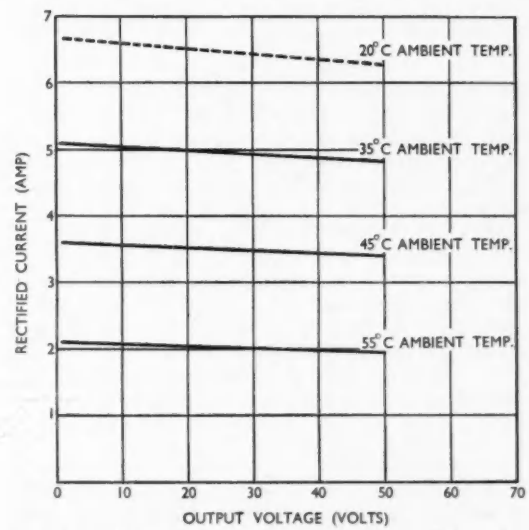

Fig. 17(a).—Maximum rectified current against mean D.C. output voltage for various ambient temperatures with bridge operation into a resistive load and EW54 diodes not fitted with cooling fins.

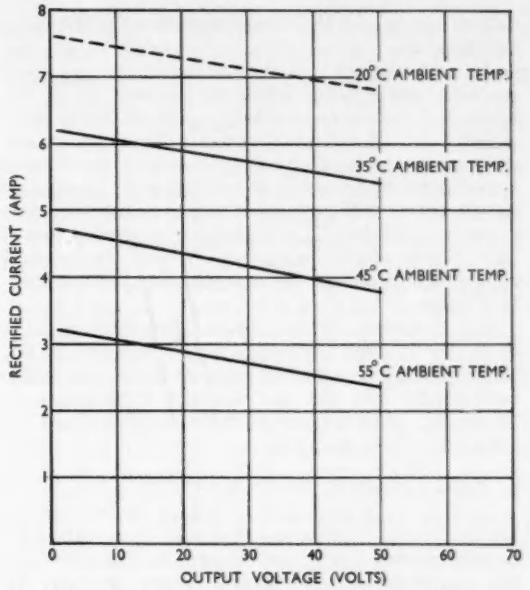

Fig. 17(b).—Maximum rectified current against mean D.C. output voltage for various ambient temperatures with bridge operation into a resistive load with smoothing choke and EW54 diodes not fitted with cooling fins.

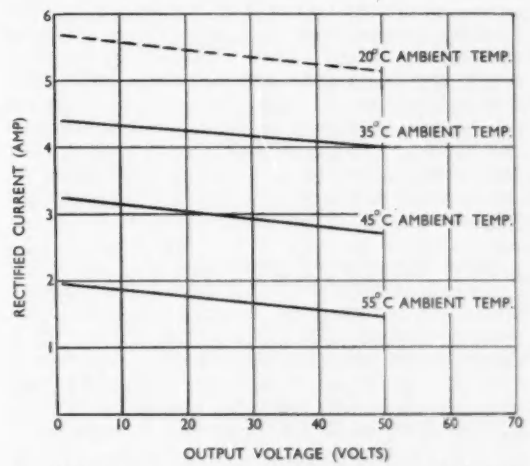

Fig. 17(c).—Maximum rectified current against mean D.C. output voltage for various ambient temperatures with bridge operation into a battery load and EW54 diodes not fitted with cooling fins.

deliver twice the D.C. output voltage at the same current.

At high current operation, the increase in diode internal temperature causes an increase in reverse current and thus an increase in reverse power dissipation. In order to compensate for the higher reverse dissipation at higher operating voltages, the forward current must be reduced. Reference to fig. 14 indicates that with a resistive load at an ambient temperature of 35 deg. C. a maximum rectified current of 14 amp at 6 volts is permissible. At an output voltage of 50 volts, however, the maximum rectified current is 12 amp.

At the maximum rating, for an ambient temperature of 55 deg. C., the allowable internal temperature rise for the diode is less than one quarter of the permissible temperature rise for an ambient temperature of 35 deg. C. As a consequence the maximum current rating is reduced to 4 amp.

(c) Operation with a Smoothing Choke.

In fig. 15, the maximum ratings are shown for operation with a smoothing choke into a resistive load. Higher current ratings are obtained in this case since the waveform of the current flowing through the diodes is almost square, so that the heating effect is less than before and a greater rectified current is obtained for a given power dissipation. The calculation of the inductance of the smoothing choke for a given percentage of ripple is given in the Appendix.

(d) Operation into a Battery Load.

The rating curves for operation into a battery are given in fig. 16. In this case, conduction through the diodes occurs when the instantaneous applied voltage exceeds the battery voltage. Due to the very low forward resistance of the diodes together with the low internal resistance of the battery, a very large current flows when the applied voltage exceeds the battery voltage by only a small amount. Hence the rectified current will consist of pulses of large amplitude and small duration. When EW54 diodes are used for battery charging, the ratio of peak to mean rectified current may be large, necessitating conductors of adequate cross section. Such a rectified current will be of relatively large R.M.S. value so that diode dissipation will be high. This fact is illustrated by the lower maximum current rating for battery load (fig. 16).

(e) Operation without Cooling Fins.

For some applications where space is at a premium, it may be advantageous to operate EW54 diodes without external cooling, for lower current rating. Rating curves corresponding to resistive and battery loads are given in fig. 17 (a, b and c). It may be seen that currents of 4 to 5 amp are obtainable with full-wave operation at 35 deg. C. ambient temperature.

(f) Regulation.

Fig. 18 shows the regulation, i.e. the variation of D.C. output voltage for a change in rectified current from zero to maximum rating with A.C. input voltage maintained constant. It is seen that the D.C. output voltage falls by 1 volt for a change in rectified current from zero to 20 amp. This is due to the low internal resistance of the diodes.

(g) Thermal Time Constant.

Although it is assumed that for the majority of applications the EW54 will be used for rectification of a sine-wave input, there are possible applications where the diode may be required to pass large forward currents for periods of time which are long compared with those involved in mains frequency rectification.

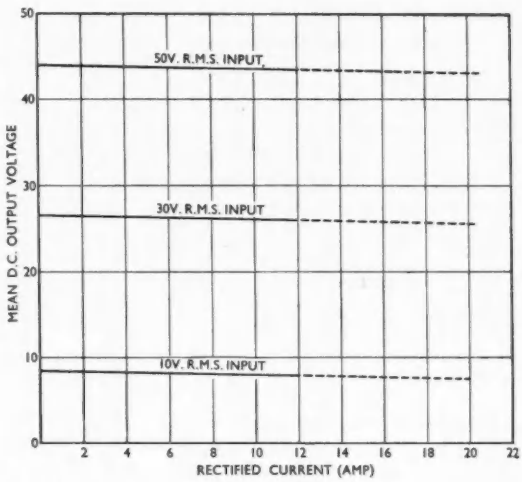

Fig. 18.—EW54 regulation curves for bridge operation into a resistive load. These curves show the variation in D.C. output voltage from full load to zero load for constant A.C. input voltage.

In such cases, it is desirable to know the thermal time constant, i.e. the time for the junction temperature to rise from ambient to a temperature $(1-\frac{1}{e})t$, where t is the temperature rise above ambient corresponding to a given diode power dissipation (e=base of natural logarithms).

A value of approximately 4 minutes is obtained for the thermal time constant, whether or not the diode is fitted with cooling fins. Thus, so long as the conduction period is very small compared with 4 minutes, and the mean diode power dissipation is within the limits prescribed by the curves of fig. 13, the diode may be used in circuits passing high current pulses.

FREQUENCY LIMITATIONS.

(a) Hole Storage Effect.

When the applied voltage swing to a p-n junction diode changes from positive to negative, the diode instantaneously behaves as a low resistance, due to the injected holes which are still present in the device. A large reverse current pulse will persist until all the holes have recombined or have been extracted. The

magnitude of the pulse will depend on the magnitude of the forward current and also on the rate of change of applied voltage. The effect, which is comparable with that of de-ionisation in a gas-filled rectifier, will thus increase with frequency so that the rectification efficiency will fall, and the diode must be de-rated for operation at higher frequencies.

In the EW54 diode, the effect is sufficiently large, particularly in low-impedance circuits, to be observed

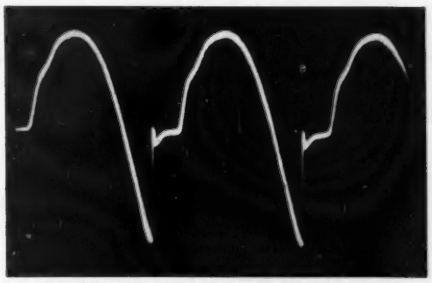

Fig. 19.—Oscillograph record of the EW54 rectifier current waveform into a battery load at a 2,600 c/s. input frequency, showing the negative peak due to hole-storage effect.

at a mains frequency of several kilocycles per second. In fig. 19 photographs of the current waveform into a battery load at a mains frequency of 2,600 c/s are shown. The reverse pulse may be seen.

(*b*) CAPACITANCE.

The capacitance of a junction diode is related to the reverse voltage (V), area (A) and resistivity (ρ) by the relation

$$C = \frac{kA}{\sqrt{\rho V}} \qquad (4)$$

k is a numerical constant.

The value of capacitance at a reverse voltage of 6 volts is approximately 240 pF. This quantity is mainly of academic and design interest, as in the majority of applications the low frequency and low circuit impedance render diode capacitance unimportant. In any case, the frequency limitations are almost completely due to hole storage effects.

SERIES AND PARALLEL OPERATION.

With the present design of the EW54, the reverse current rating is quoted to a maximum of 100 volts. If a suitable factor of safety is allowed, bridge operation is then possible to a maximum D.C. output voltage of 50 volts. There are a number of applications for which higher voltage or current are required. While use of one or other of the 3-phase bridge rectifier circuits will provide a 50 per cent. increase in output, it is necessary to resort to the use of series or parallel operation of the diodes if an increase in output voltage or current by a factor of two or more is desired.

The problem of series or parallel rectifier operation is essentially that of matching the reverse and forward characteristics respectively. Thus in the case of series operation the peak inverse voltage will be shared among the diodes in the ratio of their reverse chord resistances, so that the diode with the lowest reverse current will be subjected to the highest fraction of the total reverse voltage and may fail in an extreme case. The problem is complicated further by the variation in reverse resistance with temperature, which can result in diodes initially matched for equal sharing of the peak inverse voltage, sharing the peak inverse voltage unequally at high temperature.

Some measure of compensation may be applied by shunting each diode by a fixed resistance of such a value that small variations in reverse resistance between diodes, and temperature changes, are effectively swamped. A suitable value for a shunt resistance is 4·7 KΩ (1 W.).

Where a number of diodes are series connected, some measure of reverse voltage sharing occurs, as the diode with greater peak inverse voltage will have the highest reverse dissipation, and the heat generated will tend to lower its reverse resistance so that its share of the reverse voltage will be reduced.

Operation of the EW54 diodes in parallel is possible at full rating if the forward characteristics are sufficiently well matched to ensure that each diode takes an equal share of the forward current. In any case, equal sharing may be accomplished by including a small resistance in series with each diode. However, this method is not to be recommended as the rectification efficiency is considerably reduced.

APPLICATIONS OF THE EW54 DIODE.

Applications of the EW54 diode may be conveniently grouped into several headings :

(*a*) Resistive load (with and without smoothing).
(*b*) Battery load (including capacitance load).
(*c*) Pulse and miscellaneous applications.

(*a*) Under this heading may be grouped the use of the rectifiers for electro-plating, generator and motor field control and various magnetic amplifier applications.

(*b*) It is not considered very likely that EW54 diodes will be used in conjunction with a capacitive input filter for smoothing, as the size of capacitor even at high voltage, for the currents envisaged, would be prohibitive. However, so far as the current waveform through the rectifier is concerned, capacitive and battery loads are very similar. There are many applications of the EW54 involving a battery load and it may find considerable use in battery charging applications and also in circuits involving a resistive load and floating battery. As a typical example, the present trend in automobile electrical systems is toward A.C. generation and the use of rectifiers for battery charging. The EW54 is suitable for this application owing to its high efficiency.

(*c*) There are a number of applications for the EW54 in which the device could be used at a low duty cycle, for example, in surge prevention circuits and pulse applications where its very low forward resistance would be of value.

CONCLUSION.

The EW54 diode must be considered as the forerunner of a whole range of semi-conductor diodes. Further development work will result in diodes possessing higher reverse voltage ratings, and reverse currents several orders of magnitude lower than that of the EW54.

It is likely that silicon will replace germanium in many cases because of its improved temperature characteristics although this fact is somewhat offset by the higher forward resistance and hence greater forward power dissipation in silicon diodes for a given rectified current.

APPENDIX.

Calculation of inductance of the smoothing choke for a given ripple voltage into a resistive load.

The voltage waveform at (A) may be analysed into

$$V = \frac{4P}{\pi}\left[\tfrac{1}{2} - \frac{\cos\theta}{3} - \frac{\cos 2\theta}{15} \cdots \frac{\cos n\theta}{4n^2-1}\right].$$

The first term $\frac{2P}{\pi} = 0{\cdot}673P$ is the D.C. component, while the second term $\frac{4P\cos\theta}{3\pi}$ is the predominant A.C. component. Further terms may be ignored, because the series converges rapidly and the effect of the inductance will be greater in any case due to the higher frequency of higher terms.

The inductance is of resistance r, and the load is of resistance R, the D.C. output voltage is

$$V_{\text{D.C.}} = \frac{2P}{\pi} \times \frac{R}{(r+R)}.$$

The peak A.C. voltage across the load R due to the A.C. component is

$$V_{\text{A.C.}} = \frac{4P}{3\pi} \frac{R}{\sqrt{(R+r)^2+\omega^2 L^2}}, \quad \left[\omega = \frac{\theta}{t}\right].$$

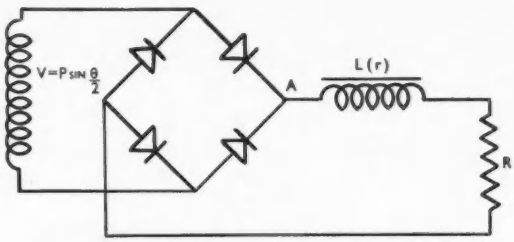

Fig. 20.—Circuit for calculation of inductance of smoothing choke for a given ripple voltage into a resistive load.

The ratio of peak A.C. voltage to D.C. voltage is

$$\frac{V_{\text{A.C.}}}{V_{\text{D.C.}}} = \frac{4P}{3\pi} \frac{R}{\sqrt{(R+r)^2+\omega^2L^2}} \times \frac{\pi(r+R)}{2PR} = \frac{2(r+R)}{3\sqrt{(R+r)^2+\omega^2L^2}}.$$

For most applications $\omega L > (R + r)$ and $R \gg r$.

$$\text{Hence } \frac{V_{\text{A.C.}}}{V_{\text{D.C.}}} \simeq \left[\frac{2R \times 100}{3\,\omega L}\right] \%.$$

Ex. Required $\frac{V_{\text{A.C.}}}{V_{\text{D.C.}}} \simeq 5\%$, for $V_{\text{D.C.}} = 50$ volts and $I_{\text{D.C.}} = 20$ amp on $50\sim$ mains.

Then $R = 2{\cdot}5\Omega$ and $\therefore L \geqslant 55\ mH$.

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Diesel-Electric Shunting Locomotives for British Railways

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Fig. 1.—One of the diesel-electric shunting locomotives in service at Hull.

INTRODUCTION.

FIFTEEN diesel-electric shunting locomotives fitted with power equipments and ancillary electrical apparatus supplied by the G.E.C. have recently entered service on the North Eastern Region of British Railways. The mechanical parts were manufactured by British Railways, who also erected the complete locomotives. The locomotive power equipments were designed to the requirements of the Chief Electrical Engineer, British Transport Commission.

The locomotives are designed for use both in flat shunting and hump shunting service. On both types of duty the diesel-electric shunting locomotive has shown many advantages, compared with steam locomotives, because of its low standby losses, ready availability and the small amount of time required for servicing.

The electrical transmission is well suited to these duties by its smooth operation and simplicity of control. Locomotives of this type have to work continuously for lengthy periods away from their depots, and to facilitate this the power equipment is of the simplest possible form.

SERVICE DUTIES.

The locomotives are designed to be capable both of flat shunting, involving the movement of trains up to 1,320 tons at speeds up to 6 m.p.h. together with the handling of lighter trains at speeds up to 20 m.p.h. ; and hump shunting, where trains up to a maximum of 1,320 tons have to be propelled at a steady speed of 1 m.p.h. over the hump. The former duty calls for a locomotive with a good performance over the whole speed range, while hump shunting requires a transmission capable of developing con-

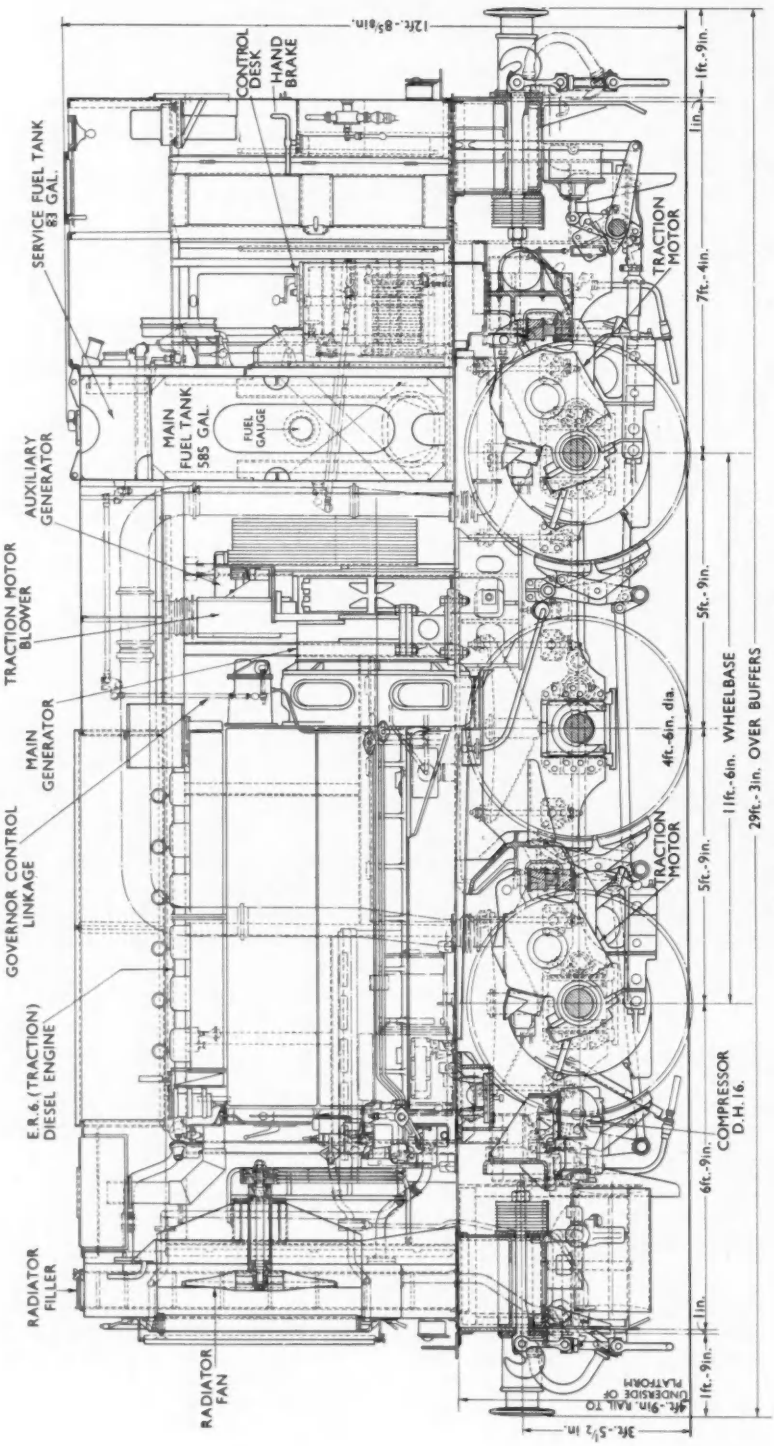


Fig. 2.—General arrangement of the locomotive.

tinuously the high tractive effort at low speed which is necessary to propel the train up the steep gradient.

GENERAL ARRANGEMENT.

The locomotives are of the rigid frame type with 0-6-0 wheel arrangement, all wheels coupled by side rods. Each outer axle is driven through double-reduction gearing by an axle-hung motor. A single end cab accommodates controls arranged for operation from either side suitable for both directions of travel. The locomotive is seen in fig. 1, while the general arrangement is shown in fig. 2.

The principal features of the locomotives are shown in Table 1.

TABLE 1.

Gauge	4 ft. 8½ in.
Length over buffers	29 ft. 3 in.
Width over platform	8 ft. 6 in.
Height	12 ft. 8⅝ in.
Wheelbase	11 ft. 6 in.
Wheel diameter	4 ft. 6 in.
Weight in working order	49 tons
Maximum speed	20 m.p.h.
Fuel capacity	668 gal.

Fig. 3.—The control cubicle.

The power unit, consisting of the engine, main generator, auxiliary generator, and blower, occupies the central position in the engine housing, which is divided into engine and generator compartments by a bulkhead fitted round the main generator. Access to the unit is by side doors.

In front of the engine is a combined water and oil radiator through which air is drawn by a fan which is belt-driven from the engine. The air enters at the front of the radiator and is discharged at the side. Hand-operated shutters are provided across the front of the radiator to regulate the air flow as required.

The fuel tank is mounted between the driver's cab and the power unit, a fireproof bulkhead separating it from the cab. A bulkhead round the frame of the main generator separates it from the engine.

The major items of control equipment are contained in a cubicle in the driver's cab on which are mounted the controller handle, reverser handle and the control key switch. An instrument panel is also mounted in the cubicle.

The controller handle and reverser handle are duplicated on each side so that the locomotive can be driven equally well from either side of the cab. Fig. 3 and 4 illustrate the cubicle. On the back wall of the driver's cab are the series/parallel switch for off-load changing of the connections of the two traction motors ; the voltage regulator for the auxiliary generator ; a hot plate ; the compressor and exhauster contactor box ; and exhauster main switch. The main ammeter and speedometer are carried on a swivelling bracket pivoted off the front wall of the cab.

The motor-driven exhauster is carried outside on the running plate, where it projects beyond the sides of the engine compartment ; and the battery, which is built in two halves, is similarly situated on both sides of the locomotive, all being protected by suitable containers.

A motor-driven compressor which supplies air for the locomotive brakes and other services is mounted beneath the main frame forward of the leading axle.

The generator cooling air is drawn from the generator compartment by a fan mounted on the engine end of the armature, and is discharged into the engine compartment. The air required by the engine for combustion is taken from the engine compartment, but since it is less in volume than the air discharged from the generator, a slight pressure, which retards

Fig. 4.—The control cubicle with covers removed to show the disposition of the equipment.

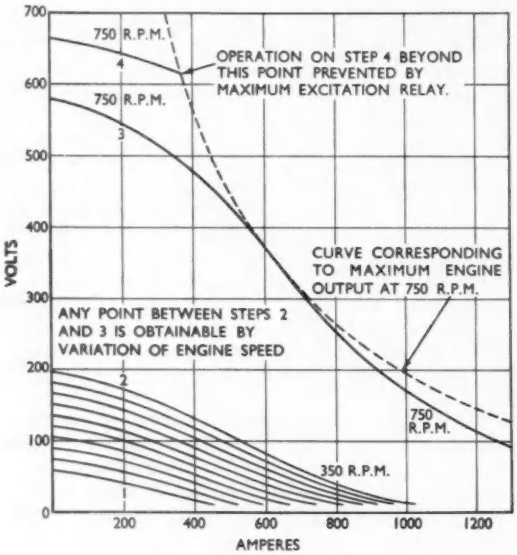


Fig. 5.—Characteristic curves of the generator.

the ingress of dirt, is created inside the engine compartment.

The traction motor cooling air is drawn from the generator compartment by the traction motor blower and is led to the motors by ducting. All air enters the generator compartment through filters located on the side doors and further filters are fitted on the air intake to the engine.

MECHANICAL PARTS.

As previously mentioned the mechanical parts were manufactured by British Railways and are to a standard design.

The main frames are of 1 in. plate carrying cast steel axleboxes and guides outside the driving wheels. Pressed-in horseshoe brasses are lined with white metal, and carbon steel laminated springs with adjustable links are provided.

The front and rear drag boxes of pressed and riveted construction, with intermediate frame stretchers and the engine bearer supports, ensure the necessary rigidity. The engine housing is of welded steel construction arranged with side doors and a sliding roof section for inspection purposes.

The fully enclosed cab is heated from the engine cooling system and is equipped with a G.E.C. electric hot plate, lighting and fire extinguishers.

The locomotive brakes are of the straight air brake type but controls are provided for controlling vacuum-operated brakes on fitted trains. The compressed air system for the brakes, sanding and whistle operates at 65/85 lb. per sq. in. Two brake cylinders of 13 in. diameter operate fully compensated brake rigging to apply two articulated brake blocks to each wheel. Automatic slack adjusters are fitted.

ELECTRICAL EQUIPMENT AND CONTROL SCHEME.

Before describing the main items of the equipment

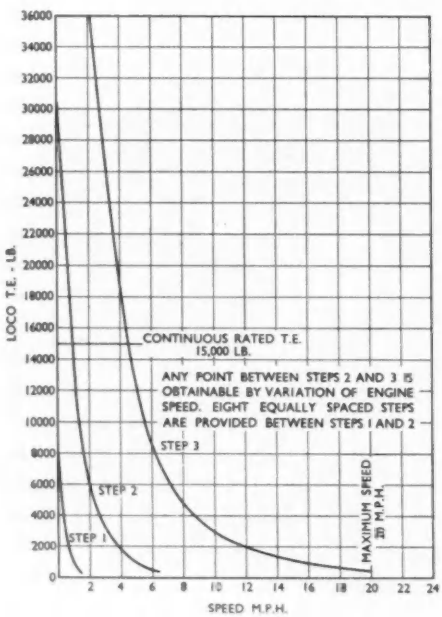


Fig. 6.—Performance characteristics of the locomotive with motors connected in series.

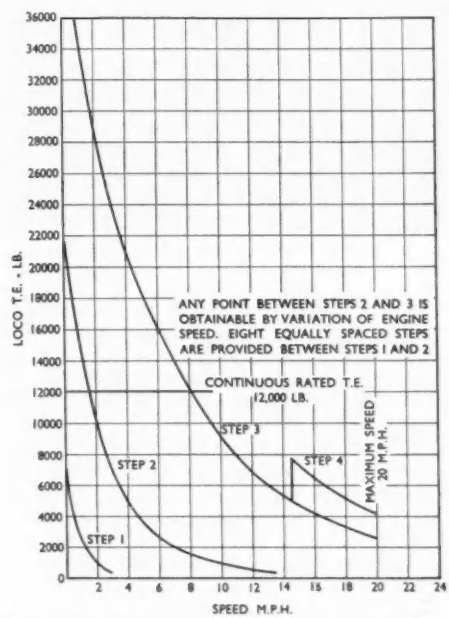


Fig. 7.—Performance characteristics of the locomotive with motors connected in parallel.

in detail, the general electrical scheme of the locomotive will be reviewed.

The function of the electrical transmission is to convert automatically the engine power output, which is at constant speed and torque, into power of variable speed and tractive effort at the locomotive wheels, the tractive effort being inversely proportional to the speed so that the power transmitted to the wheels is constant. In doing this the highest possible proportion of the engine output must be transmitted to the wheels over a wide range of locomotive speed, and any variation in this output, due to fuel quality or engine condition, or variation in electrical machine winding temperatures, must not cause overloading of the engine.

These requirements mean that although the generator demand must not, under any circumstances, exceed the available engine output, it should be as nearly equal to it as practicable, and for this type of locomotive, in the interests of simplicity, the desired result has been achieved using only the inherent generator characteristic without any external automatic regulating device. The characteristic (fig. 5) is arranged so that it closely follows the characteristic corresponding to the available engine output over a substantial part of the current range, and in order to improve the locomotive performance at the top end of the speed range, corresponding to high generator voltage, a characteristic (step 4) is provided, the use of which is restricted to this range by means of a voltage relay.

Should the generator demand tend to exceed the available engine output, the effect would be to slow the engine down, and therefore the generator is so designed that its demand falls at a greater rate with respect to speed than does the engine output. This results in output and demand balancing at a slightly lower speed and power without overloading the engine.

The size of the electrical machines on a diesel-electric locomotive is determined, among other factors, by the continuous rated tractive effort, which corresponds to the continuous rated current ; and by the maximum speed of the locomotive, which corresponds to the maximum voltage. It so happens that, for this particular type of locomotive, the duty requiring the highest continuous rated tractive effort, namely hump shunting, does not require high speeds, and therefore a significant reduction in the generator size is obtained by connecting the motors in series when hump shunting, the generator continuous rated current being determined by the lighter flat shunting duties, for which the motors are connected in parallel.

Figs. 6 and 7 show the locomotive performance curves with each connection of the motors, the continuous rating of the locomotive being 15,000 lb. tractive effort up to 4·6 m.p.h. with the motors in series, and 12,000 lb. tractive effort up to 8·2 m.p.h. with the motors in parallel. It will be seen from these characteristics that step 1 gives a curve at minimum engine speed which is suitable for handling a light locomotive or taking up slack in couplings, and this is followed by 9 notches of generator field control, all at minimum engine speed. After this, infinite variation of the engine speed up to its maximum gives the smooth acceleration and fine control of the locomotive speed which is desirable for shunting operations.

A further notch, obtained by increasing the generator excitation by movement of the master controller to its furthest extent, is provided in the parallel combination only, its use being restricted to the high-speed end of the characteristic by the overriding control of the voltage relay already referred to. This latter feature is necessary to prevent the overloading of the engine which would occur if this step were taken at lower speeds.

CIRCUIT DETAILS.

The schematic diagram is shown in fig. 8. The main generator is excited from a separately-excited field supplied from the auxiliary generator, and also has a self-excited field. The combination of these fields gives the required generator characteristic.

The supply to the traction motors is taken through isolating links and an all-electric contactor in each motor circuit. Reversal of motion is obtained by a hand-operated butt contact type reverser acting on the motor fields.

A hand-operated switch is used for selection of the motor combination, i.e. series or parallel operation.

Another hand-operated switch connects the motor circuit either to the normal generator circuit or to one including the starting field of the generator. In the latter position, with either *M*1 or *M*2 contactor closed by a special operating lever, the locomotive can be pushed or towed and the engine started by the main generator, which is supplied with current by one of the traction motors acting as a generator. This operation is required only if the battery be insufficiently charged to allow normal starting. A main ammeter indicates total generator current, and protection against earth faults is provided by the protective relay, one coil of which carries generator current and the other any fault current to earth. In case of an earth on the positive side of the equipment, the locomotive can be worked with the earth switch opened. This switch is normally sealed.

The maximum excitation relay has a coil connected across the generator so that it operates at a definite generator voltage. This causes contactor *ME* to close, shorting out resistance in the self-excited field. When *ME* is closed the self-excited field current passes through a second coil of the maximum excitation relay so making the drop voltage closer to the lift voltage than would be possible with a simple relay.

The auxiliary generator output is maintained at a substantially constant voltage by means of a carbon pile voltage regulator which is provided with a series coil carrying the battery charging current. This gives the necessary limitation of generator output when charging a heavily discharged battery.

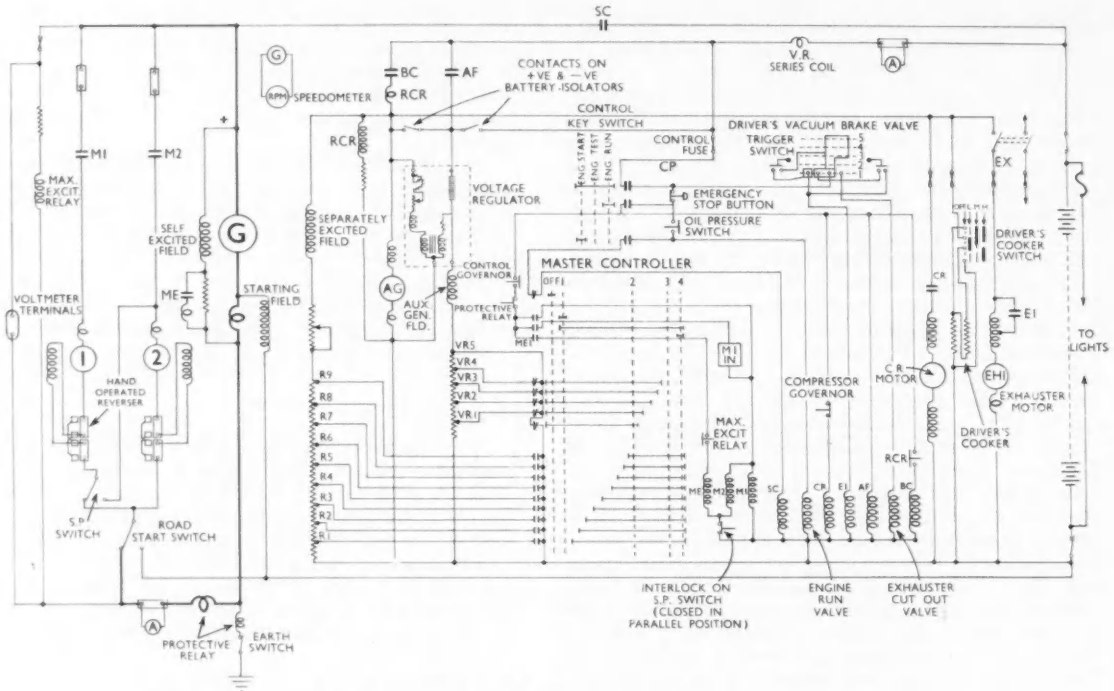


Fig. 8.—Diagram of power and auxiliary circuits.

The auxiliary generator field is excited from the battery by the closing of contactor *AF*, and the normal reverse current relay and contactor prevent the battery being discharged through the auxiliary machines.

The control key switch and master controller are contained in the control cubicle and are similar in construction. An emergency stop push button is fitted, depression of which cuts off power from the traction motors and shuts down the engine.

Dead man's pedals, one of which has to be maintained depressed, are provided at each driving position, but approximately 5 sec. delay in operation enables a driver to change from one side of the cab to the other. Release of the dead man's pedal exhausts air from the control governor, which opens the feed to the traction motor contactors, and at the same time the air brakes are applied by the operation of the emergency application valve.

Before the engine can be started, lubricating oil pressure must be obtained by the operation of a hand pump located in the driver's cab. Starting of the engine takes place when the control key switch is moved to ENG. START. This causes *SC* contactor to close, connecting the main generator to the battery.

Release of the control key allows its return by spring action to the ENG. TEST position. In this position the master controller handle can be operated to speed up the engine without any of the electrical transmission circuits being operative.

The engine speed control is by means of a system of links between the master controller and the engine governor, oil servo operation of the governor being controlled by a valve mechanically operated through the above-mentioned link gear. This provides a very light control of the engine speed. The control switch cannot be moved to ENG. RUN until the master controller handle is returned to its OFF position. Then, with the reverser thrown either to forward or reverse, the master controller handle can again be moved, but this time the electrical transmission circuits are in action.

The engine can be started only when lubricating oil pressure is adequate and the engine run valve is energised. The run valve has been specially developed for this class of locomotive. It is an electrically-operated oil valve which, when de-energised, cuts off lubricating oil pressure from the engine governor and consequently stops the engine.

The compressor and exhauster motors are fed from the auxiliary generator and run in the ENG. RUN position of the control switch except when the compressor governor cuts out the compressor or the exhauster is isolated by its main switch. High-speed running of the exhauster during release of the brakes is obtained by contactor *E*1 weakening the field and is controlled from contacts in the driver's vacuum brake valve.

The driver's hot plate, specially developed for this application, has a 3-heat control. The 40-cell

battery, of 108 AH capacity, is of the lead acid type and was supplied by the D.P. Battery Co. Ltd.

The power unit, fig. 9, consists of the Lister Blackstone ER6T diesel engine developing 350 h.p. at 750 r.p.m.; the main and auxiliary generators; and the blower for cooling the traction motors. Three-point mounting of the unit is provided on rubber resilient units, designed to fit the seatings on the standard British Railways mechanical parts. One is situated under the front end of the engine and two under the main generator.

DIESEL ENGINE.

The engine, of the E.R. (Traction) series, is a single-acting, 4-stroke, vertical 6-cylinder totally enclosed compression ignition unit, with water cooling and C.A.V. solid injection equipment.

The crankcase is of rigid box section design with a machined facing on the underside of the forward end to rest on the resilient mounting carried in the locomotive frame. The cylinder housing is bolted separately to the crankcase. The crankshaft, which is machined all over, is drilled for connecting rod big- and small-end lubrication and is fitted with an hydraulic damper which minimises torsional vibration and ensures smooth running over the whole of the working speed range.

Cylinder heads are individual units and are of the overhead valve type, embodying fuel injector, air and exhaust valves and a safety pressure relief valve for possible excess cylinder pressures. Liners are of the wet type. The pistons, embodying a toroidal type combustion chamber, are fitted with five piston rings each—three compression and two oil scrapers. The case-hardened fully-floating gudgeon pins are retained in position endwise by means of Circlips. Connecting rods are "H" section stampings, drilled centrally for small-end lubrication. The camshaft and spring-loaded centrifugal type variable speed governor are gear-driven at the flywheel end of the engine.

A wet sump lubricating system is employed, with a pressure feed from a gear-type pump to all main working parts; tappets are adequately lubricated by spray and by splash by means of overflow from the valve rocker gear.

MAIN AND AUXILIARY GENERATORS.

The main generator is a single-bearing machine, the armature being direct-coupled to the engine flywheel and the frame being flange-mounted on the flywheel housing so as to form a combined unit with the engine, thereby dispensing with the need for a separate bedplate.

Provision has been made in the generator bearing housing for limited radial adjustment of the bearing position to compensate for any wear which may take place in the engine main bearings.

The generator is a six-pole machine of robust construction specially designed for traction service, Class B insulation to traction standards being used throughout. The wave-wound armature is built up on a fabricated spider and the machine is self-ventilated by a fan mounted on the coupling disc.

In addition to the fields already described, a series field is provided for use when starting the engine from the battery, the interpoles being cut out of circuit during this operation in order to reduce the resistance of the machine.

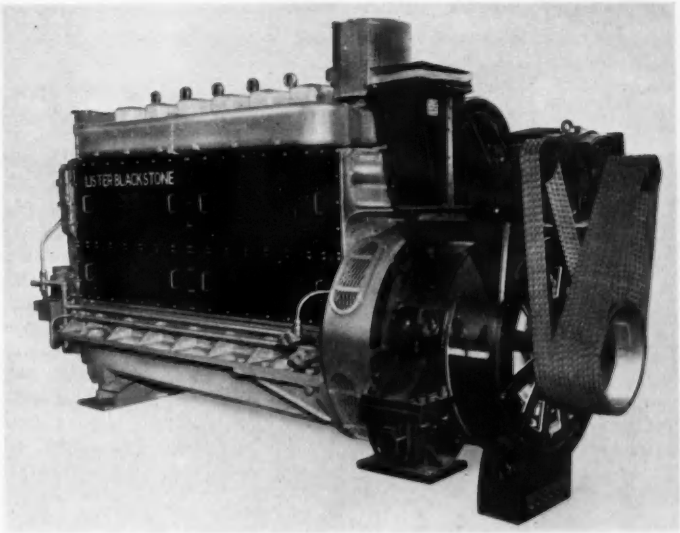


Fig. 9.—Engine-generator set.

Mounted on top of the main generator are the 8-kW, 92-volt auxiliary generator and the traction motor blower, both driven by means of liberally-rated vee-link belts from a common pulley on the main generator shaft extension. In each case provision is made for adjustment of the belt tension. These machines, together with the main generator, can be detached from the engine as a complete unit.

The auxiliary generator is a four-pole compound machine operating in conjunction with a voltage regulator. It supplies power for main generator excitation, battery charging, control gear operation, lighting, hot plate, and for driving the exhauster and compressor. As in the case of the main generator, the machine is built to traction standards and is Class B insulated throughout.

TRACTION MOTORS.

The traction motor (fig. 10) is a four-pole series wound, force ventilated machine, which is axle-hung and drives the wheels through double-reduction gearing with an overall ratio of 21·6/1. Only two brush arms are used so that access for maintenance need only be provided from below the motor.

The design of the gearcase is very similar to that used on the G.E.C.-equipped shunting locomotives operating on the Ceylon Government Railway but an additional device has been provided for demeshing the intermediate gearwheel and pinion so that the locomotive can be towed at speeds in excess of 20 m.p.h. without damage to the motors.

The hollow intermediate shaft and its roller bearings are mounted in eccentric housings which are joined

Fig. 10.—Double-reduction geared traction motor.

by a spindle passing through the hollow shaft. A square end provided on this spindle projects beyond the inner bearing cap so that it can be turned by a spanner. Two bolts lock the bearing housings in either the meshed or demeshed position, and after they have been removed, rotation of the spindle by the spanner moves the gears into and out of mesh as required.

This design allows the gears to be easily and very quickly meshed or demeshed by one man, the commutator opening and demeshing spanner being so situated that the operator can easily turn the armature to line up the gears when putting them into mesh.

The gearcase is of cast steel and is spigoted on to the motor, the suspension bearings and bracket being on the motor shell. The armature roller bearings are grease lubricated and the spherical roller bearings of the intermediate shaft are lubricated by the gear

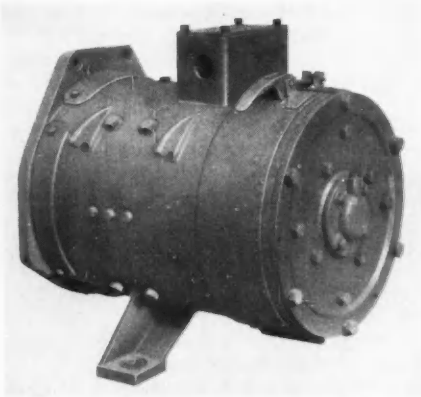


Fig. 11.—The exhauster motor, which is spigoted to the exhauster crankcase.

oil. The motor suspension bearings are of the standard waste-packed type.

EXHAUSTER AND COMPRESSOR SETS.

The Westinghouse 3V72 exhauster is driven by a motor (fig. 11) the armature of which is mounted on an extension of the exhauster crankshaft, the motor frame being spigoted to the crankcase. By eliminating the bedplate and coupling between the exhauster and a separate motor, any trouble which could arise from misalignment of the motor and exhauster due to flexing of the bedplate is avoided.

The compressor set is a Westinghouse type D.H.16 unit, driven by an integral geared motor.

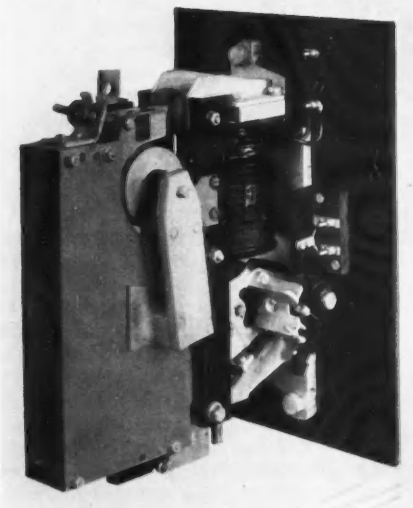


Fig. 12.—Main motor contactor.

CONTROL APPARATUS.

The items of control gear are designed to be as simple and robust as possible to meet the heavy duty and shocks inevitably encountered in shunting service.

The main motor contactor (fig. 12) is of the all-electric clapper type, arranged for front mounting and front connection. The contacts are closed by energising the operating coil and are opened by gravity. The clapper armature is pivoted on a mild steel frame and carries a spring-loaded knuckling piece to provide the correct wiping action of the contacts.

A flexible shunt carries current from the contact tip to the lower terminal, ensuring that main current does not pass through the hinge bearings. Similar protection of the knuckling spring is obtained by insulated spring seatings.

The arc chute and magnetic blowout system are of the simplest construction consistent with efficient quenching of the arc at the contact tips.

Other contactors for engine starting, field control, and auxiliary control are standard types as used in various applications for several years and embody the same features as the main motor contactors.

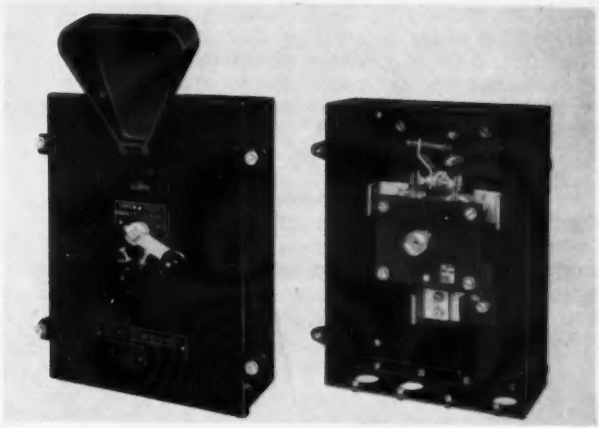


Fig. 14.—Exterior and interior views of the series/parallel switch.

REVERSER.

The butt contact type motor reverser (fig. 13) is a two-position switch, which is hand-operated through simple gearing and a toggle lever from either of the control positions on the driver's desk. Operation of one of the reverse handles on the desk rotates the shaft assembly carrying the moving contacts, which are brought into contact with the fixed contacts mounted on bases fixed to the frame assembly. A compression spring between opposite moving contacts gives contact pressure when the reverser is in an operative position. Braided copper shunts prevent current passing through the springs.

SWITCHES.

The series/parallel switch for selecting motor combinations (fig. 14) is of the butt contact type, with moving contacts carried on bases pivoted on a carrying frame. This moving-element frame rotates on a pivot pin and works against leaf springs attached to the backing plate. The frame is actuated from the handle through an eccentrically-mounted bracket carrying a roller. Contact pressure is given by compression springs located between opposite contact bases. The road start switch is of similar construction.

RELAYS.

Typical of the relays employed is that in fig. 15, which shows the battery reverse current relay. This,

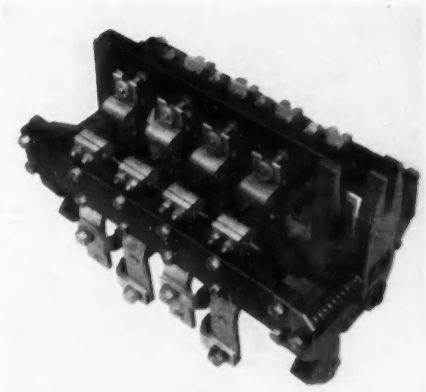


Fig. 13.—The hand-operated, two-motor reverser.

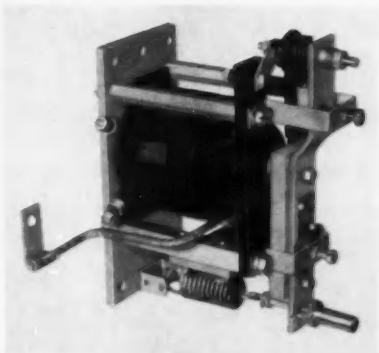


Fig. 15.—Reverse current relay.

in common with the maximum excitation and protective relays, is of the clapper type, the moving contact being carried on an extension of the clapper. The coils are mounted on a steel magnet frame and a substantial control spring ensures that the relay has a reasonable resistance to shock.

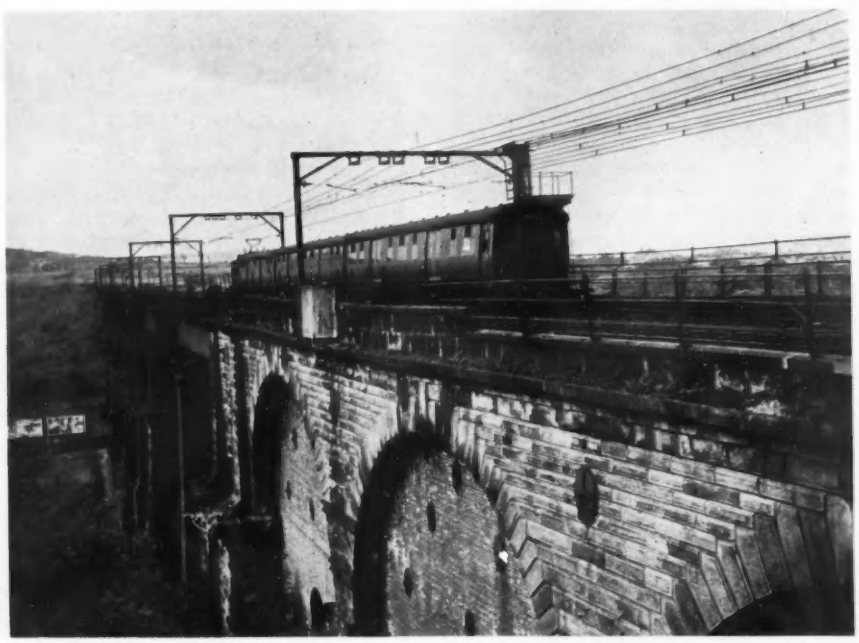
HUMP SHUNTING TESTS.

In April one of the locomotives was sent to the Southern Region for hump shunting tests at Feltham Down Yard, where the operating conditions are as severe as at any hump yard on British Railways. The approach is on a gradient of 1 in 223, after which the hump rises for 152 ft. at 1 in 83 and then for 100 ft. at 1 in 27 to the summit.

Six runs were made over the hump with two specially marshalled coal trains weighing 1,009 and 1,002 tons. Throughout the tests the engine and control equipment functioned with complete satisfaction and the records show that although the machine winding temperatures at the hump summit on successive trips were still rising after the sixth trip, the ultimate temperatures would be well below the maximum recommended in B.S.173/1941.

Rail conditions were good, the weather being sunny and dry. On one trip with each train accelerating currents of 500 amp were used, corresponding to a tractive effort of 27,600 lb., or 26 per cent. of the locomotive adhesive weight, without sanding or any sign of slipping.

Railway Electrification in the Pennines



A Manchester-Glossop multiple-unit train crossing Dinting Viaduct, near Glossop.

Electrification at Jan Smuts Airport

By H. H. JAMES, A.M.I.E.E.
Business Development Department.

THE largest airport on the African continent, Jan Smuts Airport, Johannesburg, was opened with full traffic facilities in September, 1953, replacing the temporary international airport at Palmietfontein used by internal and overseas traffic since the war. The site of the new airport was chosen at Kempton Park by the late General Smuts to fulfil his wish that the main airport of the Union should serve not only Johannesburg, but also the administrative capital at Pretoria.

The airport covers an area of just over 3,700 acres and is the home of South African Airways, a large portion of the site being devoted to their use as a Technical Area. In this area a most modern set of workshops has been built, planned to provide the best facilities for the repair, maintenance and overhaul of the South African Airways fleet.

The airport was designed and built by the South African Railways & Harbours Administration and took just over five years to complete at a cost exceeding £6 million. Bearing in mind the rapidity with which requirements in this field of transport change and the very swift growth both in size of aircraft and density of traffic which has occurred in the last few years, it says much for the foresight of all concerned with the construction and planning that on opening for traffic the airport was able to take its place amongst the largest and best equipped in the world.

The airport comprises three runways, all 200 ft. wide. The main runway, 03-21, is 10,500 ft. long and the other two runways—15-33 and 09-27—are each 8,250 ft. long. They are interconnected with the loading apron by a taxiway system comprising twelve separate sections so arranged as to provide, in addition to a route from the apron to take-off, alternative routes to the apron for aircraft landing from each of the six directions (fig. 1).

POWER REQUIREMENTS.

The power requirements of an airport are usually classified under two headings, viz :—

(*a*) The essential load, for which standby power must be provided ; and

(*b*) The non-essential load, for which standby power is not normally required.

This conception has been modified somewhat in the case of Jan Smuts Airport, and the two headings have become in effect three, as follow :—

(*a*) Vital loads.

(*b*) Essential loads.

(*c*) Non-essential loads.

Of the above (*a*) and (*b*) both require standby power. This is because a high proportion of the load is taken by the South African Airways Technical Area, where a large number of skilled operatives are employed on the overhaul of aircraft and components. The work here is naturally allied and closely co-ordinated with the operational requirements of the S.A.A. fleet, and maintenance and

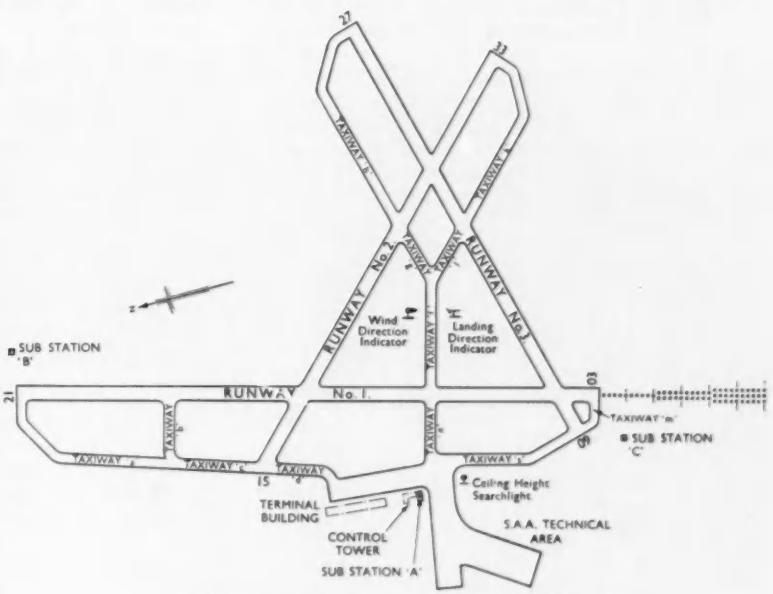


Fig. 1.—Plan of runways and approach lighting.

overhaul commitments essential to the efficient and safe operation of the airline must be met.

Under headings *a*, *b* and *c* (page 219) are included :

(*a*) All electrical services which have any bearing on the safe handling of aircraft both in the air and on the ground, and the movement of passengers and baggage. This section of the load covers quite a wide field, since in it must be included :

1. Radio navigational aids, communications and approach aids.
2. All airport lighting equipment.
3. Emergency lighting in public, baggage, and freight enclosures.
4. Public address equipment.
5. Essential power requirements for the control tower, meteorological office, and the operations offices of the various airlines.

(*b*) The various loads in the offices and workshops of the S.A.A. Technical Area, which may well have to be in full operation 24 hours a day.

(*c*) The remainder of the electrical load of the airport, the loss of which would not jeopardise operations, is included under this heading. It consists of general lighting (interior and exterior), cooking equipment loads, etc. However, when considered in relation to the whole load it is a comparatively small item and as a result shares the same stand-by facilities as the essential loads mentioned under (*b*).

The nature and magnitude of the various loads envisaged in the early stages of planning indicated that the power requirements would need very careful consideration in order to ensure continuity of supply to the vital services and an alternative supply to the South African Airways Technical Area.

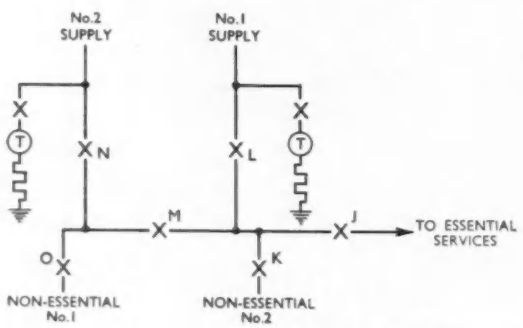


Fig. 2.—Main 6,600 V switchboard, incoming and non-essential circuits.

POWER SUPPLIES.

(1) HIGH TENSION.

The main supply is derived from the Electricity Supply Commission's network at 6,600 volt, 3-phase, 50 cycles. Two separate supplies have been provided, one each from the Isando and Elandsfontein substations, and both supplies are unearthed. The total capacity of the two feeders is approximately 5,000 kVA and neither is for the present individually capable of providing for the whole load of the airport. The main switchgear has therefore been arranged in the manner illustrated in fig. 2. Under normal conditions, i.e. with both incoming supplies healthy, main supply circuit breakers L and N are closed and the bus section circuit breaker M is open. Accordingly No. 1 supply would provide power for Non-Essential Services 2 and also the Essential Services section of the switchboard, bus coupler J being also closed ; whilst No. 2 Supply would provide power for Non-Essential Services 1.

Failure of either of the incoming supplies causes the corresponding circuit breaker to trip, followed

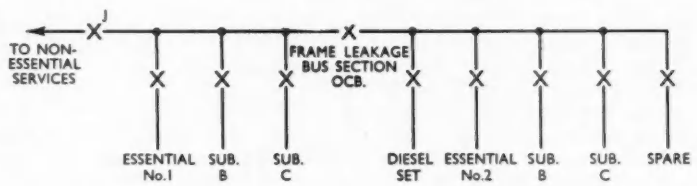


Fig. 3.—Main 6,600 volt switchboard, essential service circuits.

immediately by the automatic closing of bus section circuit breaker M. Since neither of the incoming supplies is capable of carrying the full load, circuit breaker O supplying Non-Essential Services 1 will trip out, while circuit breaker K supplying Non-Essential Services 2 will remain closed. In certain circumstances the reverse may be preferred, in which case operation of an overriding key on the control desk will cause tripping of circuit breaker K and the closing of circuit breaker O. Bus section circuit breaker J feeding essential services will remain closed.

In the event of failure of both supplies, both circuit breakers L and N will trip and in turn cause circuit breaker J to trip also, thus isolating entirely the essential services from the remainder of the switchboard. The tripping of these three circuit breakers, L, N and J, initiates the starting-up sequence of the 200 kVA G.E.C.-Ruston automatic-starting diesel generating set which feeds the essential services busbars via an oil circuit-breaker as shown in fig. 3.

Since both incoming supplies are unearthed, it was necessary to provide an earthing transformer for each supply in order that earth fault protection could be applied to the 6,600 volt distribution system on the airport. These transformers are earthed through resistances and connected by means of separate circuit

breakers to each supply. The diesel generator supply at 6,600 volts is also earthed through a resistance of similar value. Faults which may arise on the feeders to the airport without causing their immediate isolation at the supply end are detected by protective relays

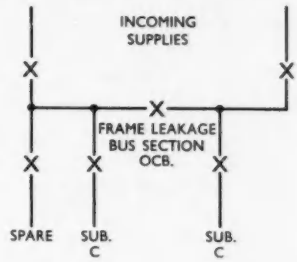


Fig. 4.—Substation 6,600 volt switchboard circuits.

at the receiving end and thereby trip the circuit breakers feeding the fault followed by tripping of the main supply circuit breakers L and N. An audible warning is also provided to call attention to abnormal conditions arising in the equipment.

The Essential Services section of the switchboard is arranged as shown in fig. 3 and the complete essential services distribution system is shown in fig. 6. The airport derives its essential supplies from three substations : a main substation A ; substation B located in the vicinity of the North end of the main runway ; and substation C located near the South end of the main runway. Substations B and C provide power for the approach lighting system and radio navigational, communications and approach aid equipment ; while main substation A feeds runway and taxiway lighting, auxiliary airport lighting equipment, and essential supplies in the terminal and control areas.

In order to safeguard supplies as far as possible, two feeders from the Essential Services switchboard have been provided to all three substations, differential parallel feeder protection being applied to each pair of feeders. In addition, the essential services section has been divided into two parts, each part being insulated from earth and connected together by means of a bus section circuit breaker. This circuit breaker is equipped with current transformers, earth fault and trip relays designed to trip it in the event of frame leakage from either section, thus providing a measure of protection against busbar faults on the essential services switchboard. In substations B and C six-panel switchboards have been provided as shown in fig. 4, again with frame leakage protection between the two incoming supplies. Two feeders, one from each side of the bus section switch, feed the low-tension distribution panels through step-down transformers, parallel feeder protection being included on both H.V. and L.V. sides.

All H.T. switchgear is of the SVD type with a breaking capacity of 75 MVA. All the circuit breakers shown in fig. 2 and the diesel set circuit breaker in fig. 3 are solenoid-operated and remotely-controlled from the power control desk at the end of the switchboard. The control desk is equipped with an illuminated mimic diagram arranged to show the state of all control switchgear and also with the necessary closing and tripping handles. Power for operating these circuits is obtained from a 110 volt Chloride storage battery.

Fig. 5 illustrates the arrangement of the power control desk and the incoming section of the main switchboard, including the earthing transformer cubicles ; while fig. 7 illustrates the manually-operated essential services section.

The diesel generating set (fig. 8) comprises a Ruston & Hornsby 6 VEB engine coupled to a G.E.C. two-bearing alternator running at 500 r.p.m. If the main supply fails, the engine is automatically started by compressed air. In normal conditions the air supply from the air reservoir is shut off by means of a low-voltage solenoid energised by a rectifier unit fed from the 230 volt supply. On failure of this supply the solenoid releases a valve and air is admitted to an air motor-driven oil pump which commences to build up oil pressure in the engine lubrication system. When this pressure has been raised to a safe figure, an oil pressure-operated valve releases starting air from the reservoir to the engine cylinders. As soon as the alternator voltage reaches normal, its circuit breaker (fig. 3) closes automatically, connecting

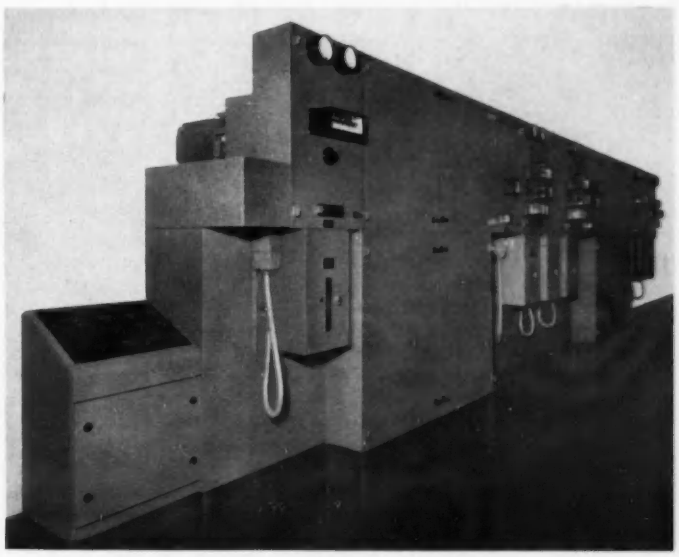


Fig. 5.—Incoming section of main 6,600 volt switchboard and control desk.

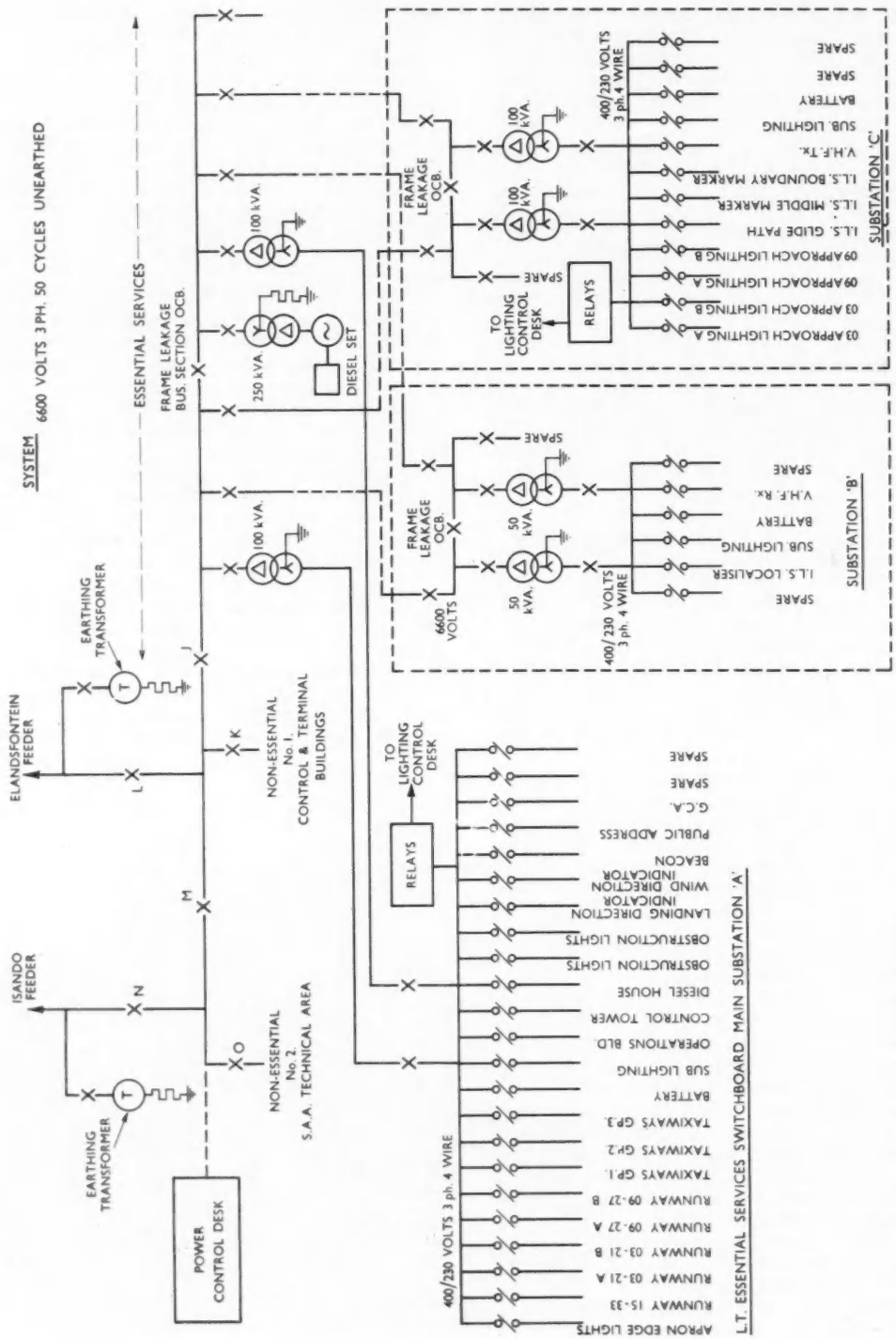


Fig. 6.—Essential services distribution diagram.

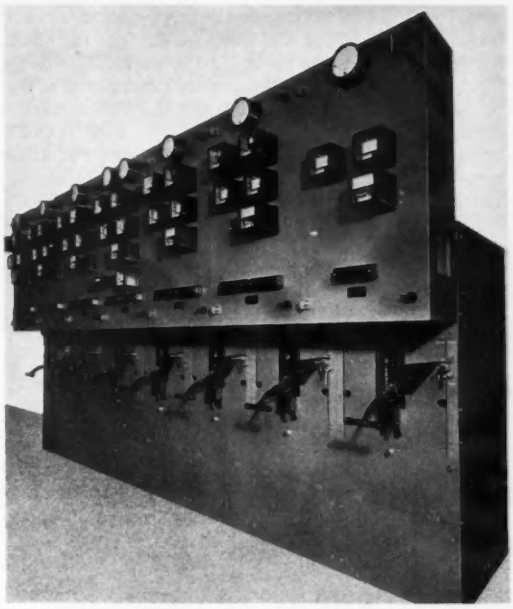


Fig. 7.—Manual section of 6,600 volt essential services switchboard.

the alternator output to the busbars. A supply thus being restored, the compressor can start up and recharge the air reservoir, the valves of which have been reclosed. In order to protect the engine against damage arising out of high water temperature, low oil pressure, or over-speed, means are provided to shut down the engine should conditions reach danger point, while an audible warning is given in the event of abnormal conditions of a less serious nature.

Should the engine shut down as a result of any of these conditions occurring, and should the mains supply not have been restored meanwhile, loss of starting air from the reservoir is prevented by energising the air control valve solenoid from a storage battery via a transfer relay. The alternator generates at 400 volts, stepped up to 6,600 volts by means of a transformer.

The distribution on the airport of non-essential services derived from circuit breakers O and K (fig. 2), was carried out by the South African Railways Administration and did not form part of the G.E.C. contract. However, it is interesting to note that either two separate parallel feeders or two feeders from a ring main have been provided for each substation.

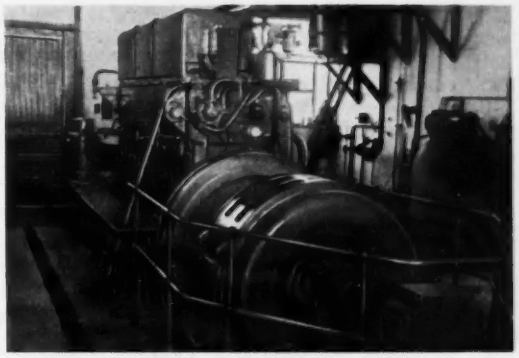


Fig. 8.—Standby diesel-alternator set.

LOW TENSION DISTRIBUTION EQUIPMENT.

The three low-tension distribution switchboards for essential services in the main substation A and substations B and C are similar in design, varying only in extent. The switchboards consist of the necessary remotely-controlled contactor panels and also manually-controlled fused-switch units. All the equipment is built into Witton universal pressed steel cubicles forming continuous and uniform switch boards each controlled by two L.T. oil circuit breakers fitted into cubicles to match the remainder of the switchboard. The switchboard in the main substation is shown in fig. 9. It will be noticed that the board consists of a combination of single- and four-tier cubicles. The single cubicles are used for multiple contactor circuits, such as for runway and group taxiway control, while the 4-tier cubicles are for

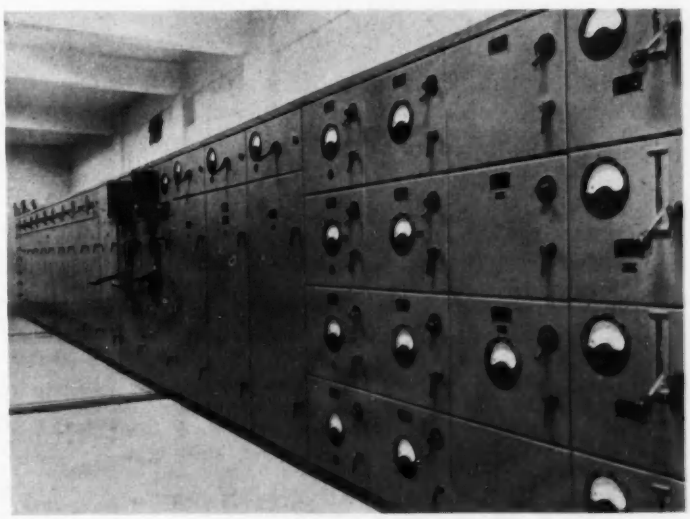


Fig. 9.—L.T. switchboard in main substation.

single-contactor or manually-operated fused switch circuits. Each single cubicle or section of a four-tier cubicle is provided with an isolator interlocked with the front door, permitting the panel to be made dead before opening. The isolators interrupt not only the main supply but also all control and indicating circuit supplies.

Fig. 10 shows the general layout of contactor gear used for control of a high-intensity runway circuit. The runway lights (described more fully later) incorporate two high-intensity directional elements and a low-intensity element which is non-directional. The left-hand cubicle in fig. 10 controls the high-intensity and the right-hand cubicle the low-intensity

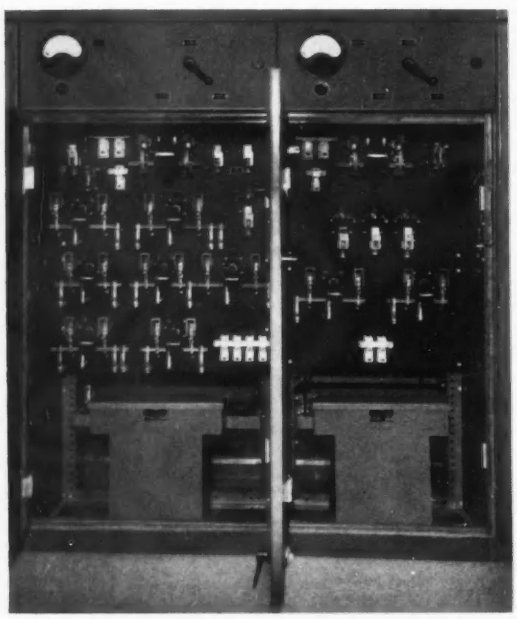


Fig. 10.—230 volt contactor board for control of high-intensity runway lights.

lights. The high-intensity lights require five selectors for brightness control and also means for selecting direction ; while the low-intensity lights require two selectors for brightness control only. In the base of each cubicle is placed a main transformer for energising the series circuits, each circuit being provided with overload and earth fault protection.

All contactors are operated remotely by means of heavy-duty telephone type relays. These are grouped as necessary in dust-proof cases and all are mounted in a single cubicle. Interconnections between the relay cubicle and the contactor cubicles are made by means of multi-core cables run in a cable trough at the rear of the switchboard. Back indication of all remotely-controlled circuits is provided by means of series load current-operated relays in each cubicle. For this purpose the 110 volt D.C. battery supply is used to signal the correct operation of the various circuits to the control desk in the tower. The low-tension switchboard in the main substation A and also in substation C are each fed by two 100 kVA step-down transformers and that in substation B by two 50 kVA transformers, all fed on the primary side from the Essential Services 6,600 volt supply. The two low-tension oil circuit breakers controlling each switchboard are arranged for simultaneous operation, and differential parallel feeder protection is provided. The transformers, although normally operated in parallel, are each capable of carrying the whole load of their respective switchboards.

AIRPORT LIGHTING.

The lighting scheme was designed to meet the requirements of the International Civil Air Organisation (I.C.A.O.), which has its headquarters in Montreal and lays down various standards and makes recommendations with regard to the equipment of international airports.

(1) Runway Lighting.

The two main runways, 03-21 and 09-27, are each equipped with elevated high intensity runway lights (figs. 11 and 12). This light combines two high-intensity unidirectional elements and a low-intensity omnidirectional element, all being separately controlled. All lights are connected in series on a 3-core 0·01 sq. in. cable forming three separate ring circuits. The base of the fitting houses three isolating transformers required for each light and this compartment is filled solid with joint box compound after the connections have been made.

The two main high-intensity beams are each adjustable in the horizontal and vertical planes, graduated scales being provided for this purpose. When fitted with 36 W lamps and with front spreader glasses, beams are obtained of maximum intensity in excess of 33,000 candelas and with a horizontal beam spread of 17°, while with a similar lamp in the low-intensity element the maximum intensity of the omnidirectional beam is 130 candelas.

The lights are placed at 200 ft. intervals along the sides of the runway except at intersections. At both ends of each row of lights, extending over the last third of the length of the row, the lights are fitted with yellow filters on the high-intensity elements facing the approach direction run for range indication in conditions of bad visibility. Thus a pilot landing will always meet white runway lights for two-thirds of the runway and yellow lights for the remaining distance. In order to meet the varying conditions of visibility the high-intensity lights are controlled in brightness in five steps as follows : maximum, 30 per cent., 10 per cent., 3 per cent., 1 per cent. ; and the low-intensity in two steps—maximum and 30 per cent.—giving in all seven steps. In order to meet the wishes of the South African Railways the control equipment was

arranged in such a way that the low-intensity element is always available at maximum brightness with any one of the five steps of brightness of the high-intensity elements.

At the junction between the lighting fitting and the underground transformer chamber is a weak connecting plate and also a disconnecting device. Should an aircraft collide with a runway light the weak plate fractures, releasing the fitting, and the disconnecting device automatically operates, thus reducing to a minimum damage both to the light and the aircraft in the event of collision.

Fig. 11.—High-intensity runway light, showing underground transformer chamber.

During the summer months the area of Kempton Park is subject to very severe lightning conditions, and it was feared that due to this interruptions to the various services would be frequent at this time of year. Accordingly it was planned that the runway lighting on the two main runways could be duplicated should operational experience so demand. With this in view the switchgear and control equipment includes all the necessary apparatus for operating a duplicate runway lighting system for these two runways.

At each end of the two main runways six elevated threshold lights are provided. These lights are similar to those just described, but embody certain modifications to the optical system to compensate for the reduction in intensity resulting from the fitting of green filters. On the high-intensity elements the spreader glasses have been replaced with clear glasses and green filters added, thus reducing the width of the beam, and increasing its intensity to compensate for the losses in the green filter. The low-intensity elements have been provided with green filters and with two extra refractors designed to increase the intensity along the axis of the runway while maintaining generally the omnidirectional characteristic of the light. Altogether 199 of these fittings have been installed on the two runways.

The third runway, 15-33, has been equipped with a low-intensity flush runway lighting system using a very well-tried fitting for installation on runways used in fair to good conditions of visibility. These lights are optically identical with the low-intensity element of the other runway lights, and for use as threshold lights have been modified in similar fashion. Again the lights have been spaced at 200 ft. intervals along the sides of the runway and in this case have been installed in special cast concrete bases. Each light is fed from an isolating transformer similar to those used in the other fittings but contained in a separate underground cast iron chamber. Brightness control in five steps has been provided as for the main runway lights. Although the full range of brightness control is not required with this light, the equipment for five steps was provided in order that it should be suitable for use in the future should it be deemed necessary, as a result of operational experience, to replace them by a high-intensity type of fitting. Ninety low-intensity fittings have been installed on this runway.

APPROACH LIGHTING.

Runway 03 was selected for instrument landing and I.L.S. equipment is installed to provide radio guidance to aircraft in the initial approach to the runway in bad visibility conditions. This comprises five separate items of equipment:

(1) The localiser, which gives an indication of runway centre line.

(2) The glide path, which indicates when the aircraft is on the correct descent path.

(3) Three range marking beacons in the approach zone.

To supplement this guidance, approach lighting comprising a six-bar line and crossbar (Calvert) system has been installed. This consists of a line of

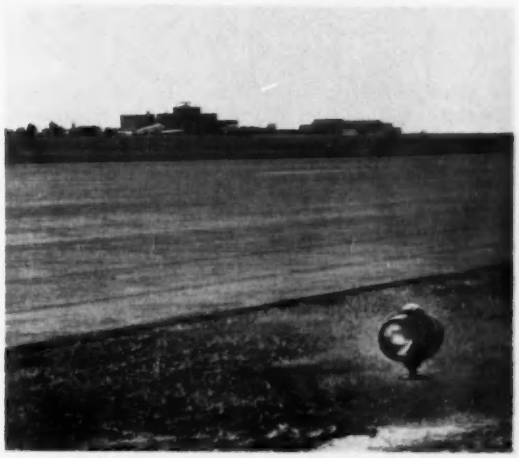


Fig. 12.—One of the high-intensity runway lights.

lights 3,000 ft. long along the extension of the runway centre line from the threshold. Lights are placed at 100 ft. intervals—a single light at each position for the first 1,000 ft., two lights for the next 1,000 ft., and three lights for the last 1,000 ft. remote from the threshold. This arrangement when being overflown gives an indication of range from the threshold in conditions when the whole of the pattern cannot be seen. At intervals of 500 ft. along the centre line are installed crossbars at right angles, decreasing in length as the runway threshold is approached.

Much has been written already about this system and it is sufficient to mention in this article that it is designed to provide visual guidance consistent with and additional to that obtained from the instrument aids so that the changeover from instrument to visual flying can take place quickly and with certainty as there is not time to revert to instruments once the changeover has been attempted. Thus the centre line provides a continuation of the information given by the localiser. The coding of the lights mentioned above provides an indication of range. Crossbars serve a dual purpose of providing artificial horizons and when passing over them the correct angle of descent can be maintained by comparing the apparent length of each crossbar with that of the preceding one, as the crossbars are designed to appear to be of equal length in these conditions.

It is considered that the system comprising the I.L.S. equipment and high-intensity approach lighting should permit successful approaches to be made in conditions down to one-eighth mile meteorological daylight visibility.

The whole approach lighting system is equipped with high-intensity approach lights fitted with 250 W Class B1 projector lamps. On the centre line the lights are fitted with clear glass, giving a maximum intensity of 80,000 candelas with a beam spread of 12°. The lights of the crossbars are fitted with spreader glasses, reducing the intensity to 30,000 candelas and increasing the spread to 30° in azimuth.

The whole system is controlled in brightness in seven steps—maximum, 30 per cent., 10 per cent., 3 per cent., 1 per cent., 0·3 per cent., and 0·1 per cent.—and is fed on two separate and independent interleaved circuits on a 460 volt, single-phase, 3-wire distribution system. Thus, in the event of failure on either circuit the complete pattern is preserved but with double spacing between lights.

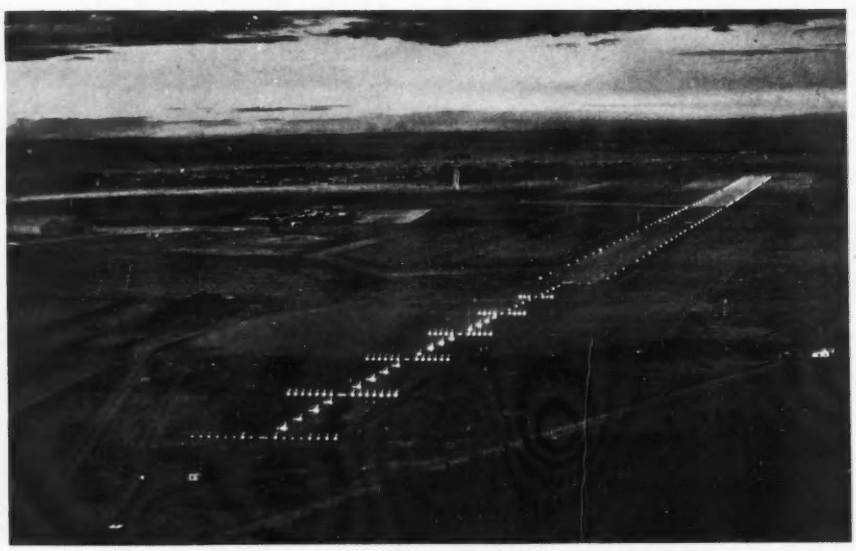


Fig. 13.—Aerial view of runway and approach lighting.

Fig. 13 shows an aerial view of the combined approach lighting and high-intensity runway lighting system in clear conditions, but it should be appreciated that in the worst conditions for which the system is designed, adequate guidance is provided when a portion of the centre line and one crossbar only are visible to the pilot.

Fig. 14 is a ground view along the centre line from the first, or outer, crossbar. In order to provide for future extension of landing facilities, full provision has been made in the switchgear and control equipment for installing a similar system on the approach to runway 09.

TAXIWAY LIGHTING.

Taxiway lighting has been provided for all sections of taxiways giving access to runways and to the

Technical Area, involving in all 14 separate circuits, a low-intensity flush fitting as on the runway 15-33 being used throughout. The lights are installed in pairs along both sides of the taxiways at a nominal distance apart of 120 ft., with reduced spacing to improve the definition at curves and bends. All lights are equipped with blue filters and are run on series circuits as for runway lights. Brightness control, however, is not provided, but these circuits are operated at a series current of 5·6 A, thus slightly underrunning the lamps, this figure giving adequate light output and greater lamp life. A total of 427 taxiway lights has been installed.

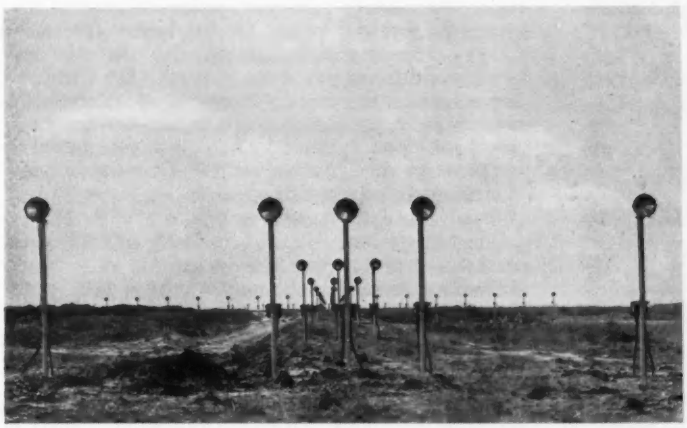


Fig. 14.—High-intensity approach lights showing grouping of centre-line units to indicate range.

Fig. 15.—Airport location beacon.

AIRPORT LOCATION BEACON.

A beacon has been installed on one of the main hangars as an additional aid to location of the airport (fig. 15). This is a four-aspect rotating lantern type beacon giving alternate white and green flashes. A $2\frac{1}{4}$ kW 100 volt Osram airway beacon type lamp is used, fed from a step-down transformer located in the base of the beacon. An automatic lamp-changing mechanism is incorporated so that on failure of the service lamp a standby is rapidly brought into the operating position and into circuit, the changeover being indicated by a warning lamp on the lighting control desk in the tower.

APRON FLOODLIGHTING.

The whole of the main apron and the access taxiway to the Technical Area is illuminated by means of special apron floodlights of long and short throw types, illustrated in fig. 16. These floodlights are designed to give a relatively wide spread in azimuth combined with a narrow spread in the vertical plane. Fitted with 1,000 W horizon type lamps, they are suitable for illuminating areas up to 800 ft. and 300 ft. in depth respectively with a mounting height of 30 ft.

Fig. 16.—Apron floodlight.

LANDING DIRECTION INDICATOR.

A standard type illuminated landing direction indicator, but fitted with a new type of power control unit, was installed (fig. 17). With the new control unit orientation of the indicator is automatic and follows the setting of the direction selector on the desk in the control tower. Remote control of the

indicator lighting is provided and back indication both of lighting and direction is included. The latter indication is given only when the unit has taken up the correct setting and come to rest.

Other items of lighting equipment include a cloud height searchlight, illuminated wind cone, and double obstruction light fittings.

Fig. 17.—Landing direction indicator.

LIGHTING CONTROL.

All airfield lighting is remotely controlled from a control console in the tower (fig. 19). The master control is the direction selector switch in the centre of the switching control panel and this has six positions. The pointer of this switch is arranged over a plan of the airport layout, the direction of the pointer indicating the direction of landing or take-off for the particular runway in use. On either side of the switch is a rotary switch for brightness control of runway and approach lighting. At the top and bottom of the panel are rows of heavy-duty telephone keys as master switches for runway approach lighting, taxiway route group switches, and switches for auxiliary lighting equipment. The keys at the bottom of the panel are for individual control of taxiway circuits, overriding the route switches.

Briefly the desk operates as follows :

The six-position direction selector is associated on the main low-tension airfield lighting switchboard with six groups of multi-contact relays, one group for each direction. Setting the switch to the particular direction required for operations at the time energises the appropriate group of relays, thus providing switching channels through which the master control keys and brightness selectors operate the final relay-operated contactor circuits controlling the airfield lighting. Individual relay groups also preselect the taxiway routes for take-off, long landing and short landing, so that very quickly the operator can select the routes required by operating a single key, thus avoiding the necessity of locating separate taxiway section keys and building up the route on the diagram.

Separate keys are provided for each taxiway section and thus are independent of the route selectors, as very often ground movements take place which are not associated with arriving and departing aircraft.

The illuminated mimic diagram forms part of the desk equipment and consists of a layout of the runways and taxiways engraved on a black-backed

Fig. 18.—Aircraft on the floodlit apron.

"Perspex" panel. Indicating lamps are provided under the panel and indicate that a particular runway, taxiway, or approach lighting circuit has been commissioned successfully. These indicating lights are switched by relays in the desk which operate as a result of the closing of relays in the switchboard operated by load current and are energised from the 110 volt D.C. substation battery supply.

A row of indicator lamps arranged vertically at the side of the mimic diagram provides indications for auxiliary lighting equipment which is independent of direction, such as obstruction lights, the wind cone, cloud height searchlight, etc.

Interlocking is provided between directional relay groups to ensure that one group only can be engaged at a time, and also to ensure that when changing from one direction to another, all keys operating directional lighting services must be returned to the "off" position before switching arrangements for equipment for the new direction can be made.

In addition, indication of the setting of the main high-tension switchgear, given on the power control desk, is repeated on the lighting mimic diagram, as the sub-station is normally unattended, and since a 24-hour watch is normally maintained in the tower this is a convenient point at which to monitor the main equipment.

In an article of this length it is not possible to describe in detail all the various items of equipment supplied by the G.E.C., which included in addition to those mentioned, large quantities of Pirelli-General cable for all airfield lighting circuits.

Acknowledgment is due to the South African Railways for their help and co-operation throughout the progress of this major undertaking, and for the use of their photographs for illustrating this article.

Fig. 19.—Lighting control console in tower.

Nuclear Power for Electricity Generation

By R. N. MILLAR, M.A., M.I.Mech.E., Manager, Industrial Atomic Energy Group.

ONE result of the International Conference on the Peaceful Uses of Atomic Energy has been a heightened public awareness of the narrowing gap between the coal mined in Great Britain and the quantity required for electrical generation. In 1954 the Central Electricity Authority had an installed generating capacity of about 20,000 MW, and 40 million tons, or one fifth of the total weight of coal mined, was needed for producing the power supplied to the National Grid. It is estimated that in only twenty years from now about 60,000 MW of electricity will be needed, which, even allowing for increased efficiency of generating plant, would require nearly half the tonnage of coal now mined for all purposes.

The difficulties in the way of increasing our coal output are first the impossibility of increasing the number of miners engaged in the industry, and, second, the fact that coal will have to be obtained from deeper levels, which ultimately results in a lower tonnage per man employed. It must also be considered whether it is wise to burn the nation's coal resources to produce power when they might be better used for producing chemicals and other products which are an essential part of modern life.

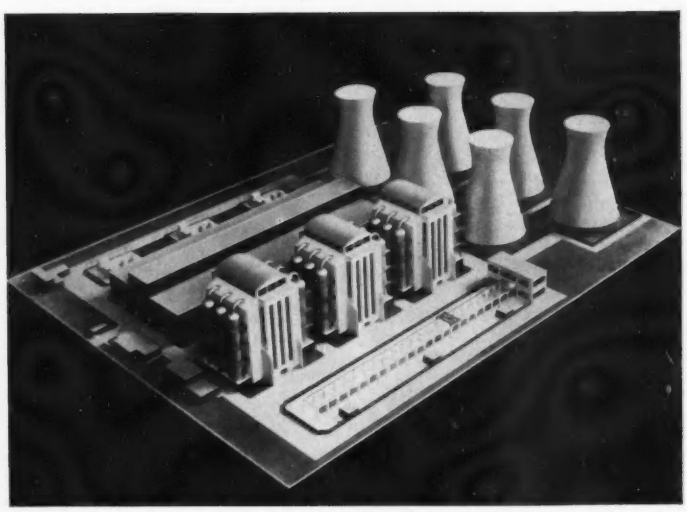


Fig. 1.—The model atomic power station shown at the First International Atomic Energy Exhibition, Geneva.

TRADITIONAL FUELS.

How then can adequate supplies of electricity be generated in future if the coal which produces it will be in such relatively short supply? The answer lies partly in the increased use of water power, partly in the larger use of oil as a fuel, and partly—eventually mainly—in the use of atomic power. At present coal supplies just under half of the world's energy requirements, oil and natural gas just over one quarter, hydro-electricity 6 per cent. and other fuels 19 per cent.

It is estimated that even if the whole of the potential water power of the world could be used and the electricity so produced could be distributed economically, it would only just meet the world's present energy requirements.

ATOMIC ENERGY.

Now atomic energy has completely changed the picture. Theoretically, one ton of uranium could produce as much heat as 2,500,000 tons of coal, but at our present stage of development it is only possible to extract part of the energy, to the equivalent of about 10,000 tons of coal. It is also expected that the cost of electricity produced from nuclear fuel is likely to be about 0·6*d.* per unit, which is not greatly different from that of coal-fired power stations.

At the Geneva conference Sir John Cockcroft, Director of the Atomic Energy Research Establishment, said that the individual capacities of the twelve projected nuclear power stations to be equipped by British industry for the Central Electricity Authority were expected to increase progressively from 100 MW to at least 200 MW, giving by 1965 a total installed capacity in excess of 1,000 MW. On the assumption that the figure reached 2,000 MW by that time, the annual saving of coal would amount to five or six million tons.

It was further forecast by Sir John Cockcroft that by 1970 most of the new British stations would be nuclear. By 1975 the nuclear capacity would probably reach 10,000 to 15,000 MW, out of a total public electricity supply capacity of 55,000 to 60,000 MW,

but as the nuclear power stations would run on base loads they would provide 40 per cent. of the kWh, thus saving at least 40 million tons of coal yearly. Probably all energy in excess of 1975 requirements would come from nuclear sources, which by the year 2,000 would be doing the work of 150 to 200 million tons of coal a year.

The discovery that the nuclear energy of certain elements can be used for power production, opens up further great possibilities. It foreshadows the rise in importance of those countries which possess deposits of fissionable material, as well as the rise of those nations who will be pioneers in their use and application.

ATOMIC POWER STATION DESIGN.

Although many of the design features of the nuclear power station are still in the development stage its general appearance will be similar to the impression which forms the cover picture of this issue, and visitors to Geneva were able to inspect the model exhibited by the Company which is illustrated in fig. 1. The main features in which such a station differs from a conventional thermal power station are seen in the three nuclear reactors with their heat exchangers and the pond for storing "hot" or irradiated cartridges of nuclear fuel. Many of the steam and electrical features of the station, together with switchgear, transformers and other auxiliary equipment, will be conventional in form. The building housing the generating plant may also contain gas coolant blowers for circulating the gas which serves as the medium for heat exchange between the reactors and the water for raising steam.

Nuclear reaction takes place as a result of the capture of neutrons by atoms of the fuel element, but the neutrons as naturally emitted are too fast and have to be slowed down by a moderator before this capture can take place. Graphite is the moderator used for reactors at present being designed for power purposes, but other moderators such as heavy water and ordinary water are under consideration for future use.

GRAPHITE MODERATOR RESEARCH.

A high-temperature, high-vacuum furnace for research into the properties of graphite moderator materials (fig. 2) was also shown at the Geneva Exhibition, together with an electron synchrotron for producing high-speed electrons for research and medicine. Both these exhibits represented work being carried out by the Company under an extra-mural research contract for the Atomic Energy Research Establishment at Harwell.

Some of the fifty-four furnaces supplied by the Company for the treatment of uranium compounds to produce uranium reactor fuel at the Springfields atomic factory were illustrated in the frontispiece to the *G.E.C. Journal* for April, 1954. This plant produces the bulk of the uranium oxide in the United Kingdom at the present time.

It is only possible to use moderate temperatures and steam pressure conditions with nuclear power plant at present in course of design, but in the future it is expected that higher temperatures will be possible, which will lead to a reduction in the size of certain sections of the plant, and particularly the turbo-alternators.

INDUSTRIAL ATOMIC ENERGY SECTION.

In all these matters of design the Company has maintained its leading position. A team of specially trained scientists—engineers, designers, physicists and metallurgists—has been at work for some time in its Industrial Atomic Energy Group at the Fraser & Chalmers Engineering Works. Plans for atomic power stations for installation in this country and overseas are in an advanced stage.

Fig. 2.—High-temperature, high-vacuum furnace for research into the properties of graphite moderator materials.

In its designs the Company is co-operating with Simon-Carves Ltd., the well-known engineers of chemical and boiler plant. This powerful partnership intends to provide complete atomic power stations designed and manufactured within its own organisations.

TURBO-ALTERNATOR DEVELOPMENTS.

Quite apart from the work which is going ahead with respect to nuclear power, the Company is also developing new designs of turbo-alternators to operate at higher steam pressures and temperatures in normal coal fired stations. The primary object of this development is to improve the overall thermal efficiency of such plant, and this leads directly to the design of much larger units than has been common practice in past years. The manufacture of larger units up to 400 MW capacity has become possible as a result of the development of the direct-cooled type of alternator described in the *G.E.C. Journal* for July, 1955.

Secondary Standard Lamps for Photometric and Colorimetric Purposes

By R. E. LEEDS, M.B.E. and G. T. WINCH, M.I.E.E., F.Inst.P., F.I.E.S.
Research Laboratories.

A description is given of an improved design of uniplanar tungsten filament vacuum lamp suitable for use as a secondary standard of directional intensity. Various ratings of improved designs of tungsten filament gas-filled lamps suitable for use as secondary standards of luminous flux are also described. In addition, data are given of the stability of good quality general lighting service fluorescent tubes of current manufacture, which, it is shown, are sufficiently stable for use to a limited extent as secondary standards in photometric and colorimetric applications.

INTRODUCTION: HISTORICAL.

SINCE the beginning of the century, first carbon and, later, tungsten filament vacuum lamps of special design have been used as secondary standards of directional intensity.[1] For operation at higher colour temperatures, specially designed gasfilled directional intensity secondary lamps were added to the range.[2]

Groups of these secondary standard lamps, calibrated in terms of a unit originally derived from the Carcel and Pentane flame standards, were used to maintain the unit of light until 1948, when, as indicated below, the primary standard of light was internationally adopted and has since formed the basis of reference.

Although a high degree of stability was required of secondary standard lamps when visual photometric techniques were used, the much greater sensitivity and rapid response of photoelectric photometers revealed, early in 1929, hitherto unsuspected momentary fluctuations of light output in many gasfilled lamps. This effect and its elimination in specially designed secondary standard gasfilled lamps were touched on in an early publication[3] but have not been published in detail. It may, therefore, be useful to record in the present article the main findings at that time and the design features of the gasfilled lamps made in 1929. These were suitable for use as secondary standards of luminous flux, and although improvements have been made in the recently designed range of lamps of this class, the basic design is similar.

Momentary fluctuations of light from gasfilled lamps were first noticed in general lighting service lamps with pear-shaped bulbs when operated pendant, cap-up, in a photoelectric photometer. When the same lamps were operated cap-down, however, they were seen to be free from these fluctuations.

Special types of gasfilled secondary standard lamps of the form shown in fig. 1, were therefore developed at that time, in which the spiral filaments were mounted in a complete wreath, the leading-in wires and supports being welded to the filament, the two semi-circular sections of which operated in parallel. This assembly was mounted centrally in a spherical bulb with a mica baffle at the entrance to the cylindrical neck. Freedom from turbulence of the gas was thus assured, whether the lamps were operated cap-up or cap-down. When these lamps were tested they were shown to be free from momentary fluctuations in light output.

The welding of the filament to the supports and leading-in wires ensured reproducibility of the electrical characteristics to a high order of accuracy, and this, together with the other design features, resulted in a lamp having a satisfactorily small rate of change of luminous flux throughout life. An additional feature was the symmetrical polar distribution of light resulting from the centrally-mounted complete wreath filament construction, which was incorporated in order to facilitate the accurate determination of the luminous flux from polar distribution measurements. This feature also minimises errors which may arise due to imperfections of photometric integrators when the lamps are used to calibrate integrating photometers.

A batch of 100 volt, 100 watt luminous flux secondary standard lamps of this design was supplied to the National Physical Laboratory in 1929 and it is understood that they have given satisfactory service since that time. Similar lamps have been in regular

use in the G.E.C. Photometric Standards Laboratory and have also been supplied for use in calibrating commercial photometers in the laboratory and in the Lamp Works of the Company over the past 25 years.

More recently there has been a requirement from national and other photometric standardising laboratories for even more stable secondary standard lamps in several ratings. This requirement has probably resulted from the steady improvement in photometric and colorimetric techniques and the consequent increase in the accuracy of measurements of this class, together with the realisation in practice and the adoption internationally of the Primary Standard of Light referred to below.

THE PRIMARY STANDARD OF LIGHT.

In 1948, on the recommendation of the Commission Internationale de l'Eclairage (C.I.E.), the Bureau Internationale des Poids et Measures (B.I.P.M.) adopted the new unit of light, the candela, based on the luminance of a full radiator at the temperature of solidification of platinum.

Fig. 1.—The 1929 design of 110 volt, 100 W, luminous flux secondary standard gasfilled lamp.

Although the primary standard of light can be reproduced from specification to a high accuracy, of the order of 0·1 per cent. in luminance, to realise it in practice involves very special apparatus and techniques, only suitable for use in photometric standardising laboratories specially equipped for the purpose, such as the National Physical Laboratory.

SECONDARY STANDARDS : IMPROVED DESIGN REQUIREMENTS.

In consequence of the situation referred to above, there is a continuing requirement for tungsten filament vacuum and gas-filled secondary standard lamps, as they are convenient for use in transferring the unit of light from the primary standard, and as secondary working standards.

Special difficulties arise when making photometric and colorimetric measurements on tubular fluorescent and other types of electric discharge lamps because of the difference in spectral distribution from that of the tungsten filament secondary standard lamps with which they must be compared.

A need has arisen, therefore, for secondary standard electric discharge lamps or, alternatively, for methods of measurement which will be free from errors when taking the step from tungsten filament secondary standard lamps to lamps of these different forms of spectral distribution. This latter problem has been solved in the standardising laboratory by the use of physical photometers and colorimeters which simulate the C.I.E. Standard Observer.[4, 5] These specialised forms of physical photometer and colorimeter are, in general, too expensive for use other than in the standardising laboratory, so that there is a demand for secondary standard tubular fluorescent lamps of the various off-white colours for use in calibrating, by pure substitution, the more commercial classes of photometer used in industry.

In the following sections of this article, therefore, brief descriptions are given of a range of tungsten filament directional intensity and luminous flux secondary standard lamps incorporating recent design improvements. These lamps have been developed in collaboration with the Photometry Section of the N.P.L. with a view to establishing a useful range of ratings of secondary standards of mutually acceptable design and performance. Details are also given of the performance of selected and aged good quality tubular fluorescent general lighting service lamps of current manufacture which are suitable for use as secondary standards, although perhaps to a somewhat more limited extent than is possible with the very stable tungsten filament secondary standards.

SECONDARY STANDARDS OF DIRECTIONAL INTENSITY : UNIPLANE TUNGSTEN FILAMENT VACUUM LAMPS.

As indicated at the beginning of this article, tungsten filament lamps of uniplane construction have for many years been successfully used as secondary standards of directional intensity, but they have sometimes suffered from limitations arising from lack of robustness, which has been an embarrassment when transporting the lamps. Another limitation has been the irregular intensity distribution at small angles from the normal. In the past, in order to eliminate errors which might arise from this cause when setting up lamps on the photometer bench, it has been necessary to mount the lamps in special N.P.L. pattern holders which critically locate the filament with respect to the photometer bench. Recent investigations have shown that specular reflection of the filament from the glass supporting system is largely responsible for these irregular variations of intensity at small angular departures from normal. In a new design of lamp these specular reflections have been eliminated by acid-etching the glass supporting frame so that it has a matt surface.

A lamp in which the glass supporting frame is etched in this manner is shown in fig. 2, from which

it will be seen that the glass frame has two supports to the pinch instead of one as in previous designs, thus greatly improving robustness of the lamp. In this new design of lamp the separate hairpin-shaped sections of the filament are mounted in one plane as before, and each filament limb is spot-welded to its lower supports, the top of the hairpin being held by critically tensioned springs.

An additional improvement is a new type of getter which enables the filament to be operated at 2,400 deg. K. with the same, or better, maintenance of intensity through life compared with early designs using phosphorous getter, where the operating temperature for the same performance was approximately 2,360 deg. K. These lamps have been made in the ratings shown in Table 1.

TABLE 1.

Lamp Description	Nominal volts	Nominal watts
Vacuum directional intensity secondary standards with uniplanar filament	100-110	30
Ditto	100-110	75
Vacuum or gas-filled luminous flux secondary standard with complete wreath filament	100-110	100
Ditto	100-110	200
Gas-filled luminous flux secondary standard but with incomplete wreath filament	210-230	40 60 100 150 200 500
(These lamps can be supplied evacuated, when they will have a different rating from that indicated in Col. 3.)		

NOTE.

All the above-listed lamps have the filaments welded to lead-in wires and supports, with the exception of the vacuum uniplanar lamps, in which only the lower legs of each hairpin-shaped limb of the filament is spot-welded, the top of the hairpin being supported by a critically tensioned spring.

SECONDARY STANDARDS OF LUMINOUS FLUX : VACUUM AND GAS-FILLED LAMPS.

A range of luminous flux secondary standard gas-filled lamps has been developed of the same general form as that shown in fig. 1 but incorporating improvement in details of the design (fig. 3). These are of the ratings indicated in Table 1, and fig. 4 shows a selection of lamps from the 40 to 500 watt range of ratings.

In order to achieve the required stability, the tungsten filaments are selected from helical coils, normalised by heat treatment to prevent any initial sagging. In the 100-110 volt ratings the filament is mounted in the form of a complete wreath which is clamped and spot-welded to the leading-in wires and then arc-welded in a reducing atmosphere to the molybdenum support wires. This eliminates minor changes in electrical stability such as can occur in

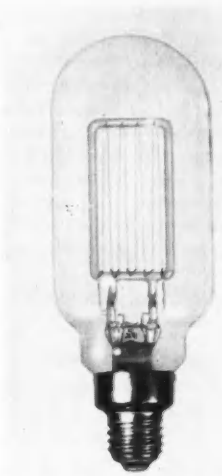


Fig. 2.—New design of uniplane tungsten filament directional intensity secondary standard vacuum lamp.

general lighting service lamps, where the filament is held loosely in a loop type of molybdenum wire support.

The filaments of the 210-230 volt ratings are of incomplete wreath form but in all other respects are mounted and welded in a similar manner to the 100-110 volt ratings.

The filament assemblies are sealed into spherical lime-soda glass bulbs specially selected for freedom from striae. By mounting the filament centrally in this spherical form of bulb, and fitting a mica disc at the entrance to the neck, turbulence of the filling gas is minimised, with consequent stability of light output.

While lamps of the form indicated above are normally gas-filled there has in the past been a small

Fig. 3.—New design of 110 volt, 100 W luminous flux secondary standard gas-filled lamp.

requirement for vacuum lamps of the same filament form. This requirement is met by evacuating, instead of gas-filling, lamps identical in all other respects. These vacuum lamps are sometimes used in the process of transferring the unit of light from directional intensity secondary standards to standards of luminous flux.

TUBULAR FLUORESCENT LAMPS AS SECONDARY STANDARDS.

In addition to recommendations at the C.I.E. meetings in 1948, and later in 1951 and 1955, that improved forms of tungsten filament secondary standard lamps should be developed, it has also been recommended that special forms of discharge lamps should be developed for use as secondary standards.

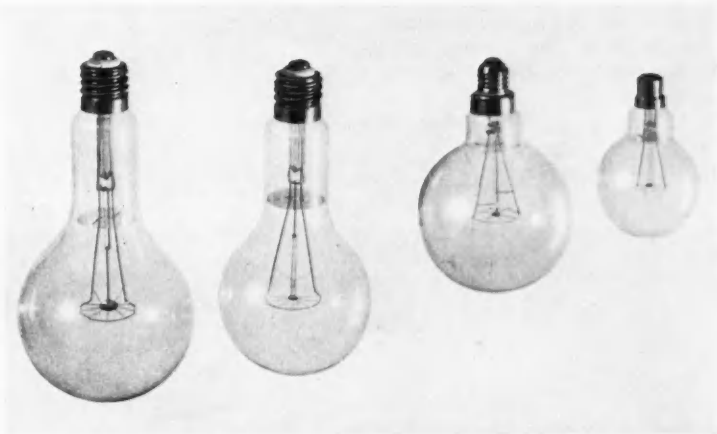


Fig. 4.—A selection from the range of luminous flux secondary standard gas-filled lamps— 110 volt, 100 and 200 W, 210-230 volt, 40, 60, 100, 150, 200 and 500 W ratings.

None has yet become available, but a study has been made of the stability of tubular fluorescent lamps of the general lighting service types and has yielded some extremely interesting and useful results. Over the last few years, data have been accumulated on the stability of light output of the more common ratings of off-white colours of these fluorescent tubes. Results have shown that good quality general lighting service fluorescent tubes of current manufacture now have a much greater stability than similar tubes in earlier years, and that, if first aged for at least 500 hours, they are suitable for use to a limited extent as secondary standard lamps.

PERFORMANCE OF SECONDARY STANDARDS.

The results of extensive measurements of the repetition accuracy of lamps of the several types referred to in the earlier sections of this article, and also measurements of these lamps throughout their useful life, indicate the stability which has been achieved. It has been customary in the past to refer to the performance of tungsten filament secondary standard lamps in terms of the rate of change in intensity or luminous flux per hundred hours after the initial ageing period, the lamps being operated on a D.C. supply. Such lamps are aged on D.C. because when they are used in photometers it is usual to operate them from batteries in order to achieve the necessary degree of constancy of voltage and consequently light output, and it is known that the rate of change of light output is usually greater on D.C. than on A.C.

All the tungsten filament lamps referred to in the present article have been aged on a D.C. supply.

An analysis of measurements on the classes of vacuum and gas-filled tungsten filament secondary standard lamps referred to in this article, which have been in regular service over the past five years, has shown that after the appropriate preliminary ageing, the types and ratings indicated in Table 1 change, on the average, at the rate of about 0·001 per cent. per " occasion of use ". " Occasion of use " in this sense means that the lamp is switched into circuit and the voltage slowly increased up to the operating voltage, at which it is maintained for about five minutes before the photometric measurements are made. The figure given above for the rate of change per occasion of use was derived from measurements on lamps which have been in regular service as secondary standards for five years, and it is expected that the change per occasion of use in service of those of improved design will be at least as good as that of the earlier lamps.

The reason for the above analysis is to enable comparison to be made with the performance of tubular fluorescent lamps, in which the rate of change of light output is dependent, not only on the period of burning, but on the number of switching cycles. Lamps of this class are, in general, designed for operation on A.C. and are, therefore, aged and operated in photometers on A.C.

With respect to fluorescent tubes, "occasion of use" implies operation on A.C. for 15 minutes until thermal equilibrium is reached, and continued operation for a further five minutes or more during which time the measurements are made.

Good quality general lighting service fluorescent tubes of current manufacture, after 500 hours' ageing, show a rate of change of about 0·01 per cent. per occasion of use. Although these fluorescent lamps are an order less stable than tungsten filament lamps, nevertheless fluorescent tubes having this performance could be used successfully in intercomparisons involving a limited number of occasions of use. In fact, one of the authors has successfully used such tubes in an unofficial intercomparison between his laboratory and two other laboratories in the United States.

In order to obtain the performance indicated above for fluorescent tubes, it is essential that special attention should be given to the method of operation. It may, therefore, be useful in this connection to indicate the operating procedure used when measuring the tubes which showed the high stability quoted in this article.

The tubes were aged for not less than 500 hours before being put into use as secondary standard lamps. During measurements the tubes were operated at rated watts and the arc volts and current recorded, together with the ambient temperature on which the light output and electric characteristics are critically dependent. Before each measurement, the tubes were stabilised for 15 minutes in the measuring circuit. During measurement they were in the horizontal position and the cathode terminals short-circuited.

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Sodium Light for Coal Picking

Satisfactory discrimination between dirt and coal by the light of sodium lamps on this picking belt at Lady Victoria Colliery, near Edinburgh, has led to four more belts being equipped similarly.